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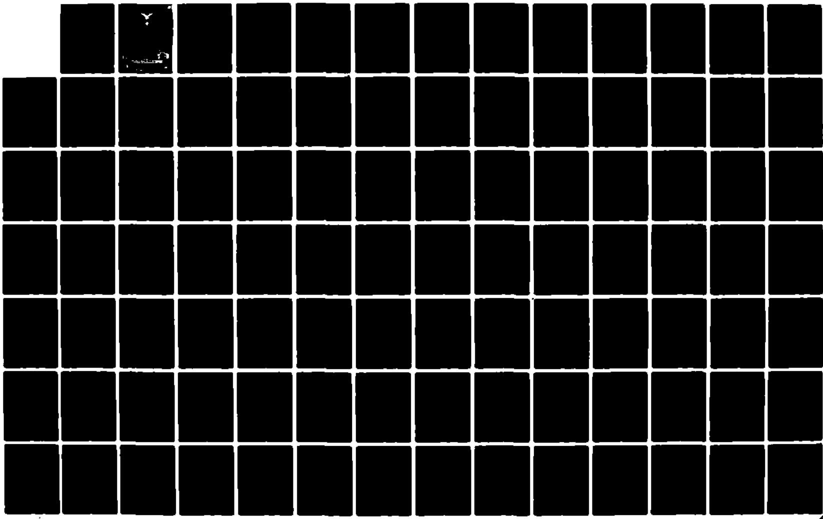

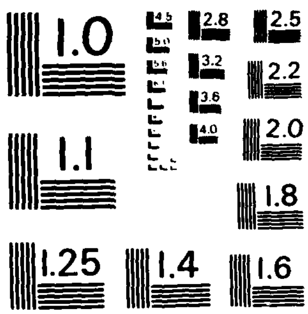

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A Q-GERT ANALYSIS OF THE EFFECT OF IMPROVED AUTOMATIC TESTING ON F-16 AIRCRAFT AVAILABILITY

Joseph C. Benner, Captain, USAF
Peter M. O'Neill, Captain, USAF

LSSR 2-83

DEPARTMENT OF THE AIR FORCE
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Wright-Patterson Air Force Base, Ohio

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Weapon systems and their associated maintenance task complexity have exceeded the limited technical capabilities of today's maintenance personnel. The present maintenance philosophy which relies heavily on Automatic Test Equipment (ATE) to narrow this complexity-capability gap has several shortcomings. Primarily, the false pull of properly functioning units and the false alarms of Built-in-Test equipment (BITE) result in increased maintenance actions, costs, and aircraft downtime. Implementing systems theory through the Systems Science Paradigm, the authors developed a Q-GERT model of the F-16 maintenance diagnostic process via a queueing scenario of the F-16 Low Power Radio Frequency (LPRF) repair cycle. F-16 Centralized Data System (CDS) data input~~ted~~ to the model showed that a simulation model is representative of the actual repair process. Sensitivity analysis indicated that reduced diagnostic error rates significantly affect the time required to generate F-16 aircraft to an operationally ready state. Increased emphasis toward decreasing false alarms and false pulls was recommended.

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A Q-GERT ANALYSIS OF THE EFFECT OF IMPROVED AUTOMATIC TESTING ON F-16 AIRCRAFT AVAILABILITY

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

Joseph C. Benner, BS
Captain, USAF

Peter M. O'Neill, BA
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September 1983

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This thesis, written by

Captain Joseph C. Benner

and

Captain Peter M. O'Neill

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 28 September 1983

Russell M. Genet

COMMITTEE CHAIRMAN

READER

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CHAPTER I

INTRODUCTION

General Issue

Today's weapon systems and their associated maintenance tasks are extremely complex. The present U. S. defense policy, which relies heavily on qualitative superiority in weapons design and implementation, requires equally superior maintenance support and equipment. As weapon systems became more electronically complex, manual equipment testing and fault detection became impractical. The solution seemed to be automatic testing with mechanized and, ultimately, computer-controlled devices. Generically, all of these devices are known as Automatic Test Equipment (ATE), officially defined as follows:

> Devices designed and capable of automatically measuring selected parameters of an item . . . being tested and making a comparison to accept or reject measured values in accordance with predetermined limits. (School of Systems and Logistics, 1981, p. 79)

ATE was initially supposed to bridge the gap between the highly complex device and the more limited skills of the average maintenance technician. This strategy had shortcomings which are now becoming apparent. Built-in-Test Equipment (BITE or BIT) is internal to the weapon system and allows operator or technician on-line fault detection and

isolation. The "false pull" occurs when the BITE identifies a malfunctioning component but subsequent diagnostics show no apparent equipment failure. These false pulls are budget breakers in terms of money and man-hours. Several studies indicate unnecessary removal rates on modern weapon systems to be anywhere from 20 to 89 percent (Herner, Miller & Genet, 1981; Institute of Defense Analyses, 1981; King, 1982).

Background

Heavy reliance on electronics in advanced weaponry has created an urgent need for faster and more sophisticated testing methods. Approximately one-third of the Air Force equipment inventory is electronic. Furthermore, the 270 million dollar 1982 funding for electronics research was more than the total request for weaponry, flight vehicles, or propulsion and power research (Bryson, Husby & Webb, 1982). Avionics is a particular breed of electronics vital to virtually all advanced airborne weapon systems. Economically, avionics comprise approximately one-half the total value of modern aircraft (Owens, St. John & Lamb, 1977). Associated maintenance costs for avionics are also on the rise due to:

> (1) an exponential increase in avionics complexity with respect to time and (2) the inflation of people costs in this labor intensive field. (Owens, St. John & Lamb, 1977, p. 1)

Reducing avionics maintenance became a high level attention item with regard to the above costs. One solution, automatic testing, was proposed to provide more precise

measurements, greater reliability, fewer human errors, and reduced testing and training costs. These benefits did not appear quickly, and, in fact, the rapid rise of ATE caused significant problems involving virtually all operation and maintenance aspects (Gutmann, 1980). The military application of ATE to weapon systems resulted in unforeseen design, training, and operational problems. ATE was originally designed to help solve the problem of high weapon systems complexity and dwindling highly skilled technicians. However, high error rates negated these benefits.

> With a 30% false pull rate, it is easy to understand the concern of the Air Force in . . . designing new systems such that BIT (Built-in-Test) will inherently have a lower rate. (Herner, Miller & Genet, 1981, p. 1)

In reducing this error rate, design must include better tolerance indications and ease of making tolerance changes in the field. Also, the environmental effects on decision error rate must be included in the design phase (Herner, Miller & Genet, 1981).

The airline industry, as well as the Air Force, is making increasing use of BIT. However, airline maintenance personnel have widely ignored BIT systems because of the lack of agreement between the BIT fault indication and the flight crews' reported discrepancy. An unnecessary removal is defined as a unit removed from the system that does not contain a failure when examined at a subsequent level of maintenance. "Airlines find that far less than 50 percent of

boxes removed contain verified failures" (Institute of Defense Analyses, 1981, p. 7).

In the Air Force, the problem in the field is not the detection of the fault but rather too many false alarms.

> BIT equipped weapon system electronic subsystems (and equipment) being introduced into the field are not meeting the diagnostic specifications which are generally in the range of 90 to 95 percent probability of automatic (or semi-automatic) fault detection and isolation. . . . experience shows that 20 to 40 percent of the items which were replaced because of a failure indication by BIT are later found to have no failure. (Institute of Defense Analyses, 1981, p. S-2)

A false alarm is defined as "an operator reported failure indication that cannot be confirmed by maintenance personnel" (Institute of Defense Analyses, 1981, p. S-5). A study at Rome Air Development Center (RADC) involving nine different Air Force systems at numerous bases found unnecessary removal rates on the order of 40 percent with some systems as high as 89 percent (Institute of Defense Analyses, 1981).

Removal of units from the aircraft is performed by Organizational level (O-level) personnel and tested by Intermediate level (I-level) technicians using ATE. The situation where O-level maintenance verifies the reported fault but I-level maintenance tests the unit and finds no fault is termed a Retest-OK or RTOK (Institute of Defense Analyses, 1981). A similar situation occurs on the flightline when the O-level technician troubleshoots a reported malfunction but is unable to reproduce the symptoms. This is termed a Cannot-Duplicate or CND condition. RTOK and CND rates

> imply that significant personnel and equipment resources are expended troubleshooting, removing, retesting, and replacing "good" avionics, thus reducing aircraft availability and increasing support costs. (King, 1982, p. 1)

In 1970 the Deputy Secretary of Defense requested proposals for new weapon systems which would help stem exponentially rising defense costs. The Air Force proposal called for a new lightweight fighter, the YF-16. When selected to join the inventory, the F-16 Fighting Falcon carried with it many new complex systems. The sophisticated avionics system included radar, an Inertial Navigation System (INS), flight control computer, communications equipment, and fire control system. An integral component of U. S. defense, the F-16 must be kept operationally ready. "It may be safely predicted that the F-16 will be in quite a few Air Force inventories, and no doubt in our own, well after the year 2000" (Norton, 1983, pp. 10-14).

As a front line fighter replacement for the F-4 Phantom, the F-16 maintenance plan makes extensive use of Self Test (ST), BIT, and ATE as diagnostic aids in maintaining this highly complex weapon system. ST is defined as

> test equipment that performs, through test sequences, two or more individual tests without requiring initiation by or assistance from the operator. (School of Systems and Logistics, 1981, p. 617)

Figure 1 indicates the current F-16 ST/BIT Support Concept (General Dynamics, 1975). The general requirements for the F-16 System specification (16PS001) states that the ST/BT requirements are:

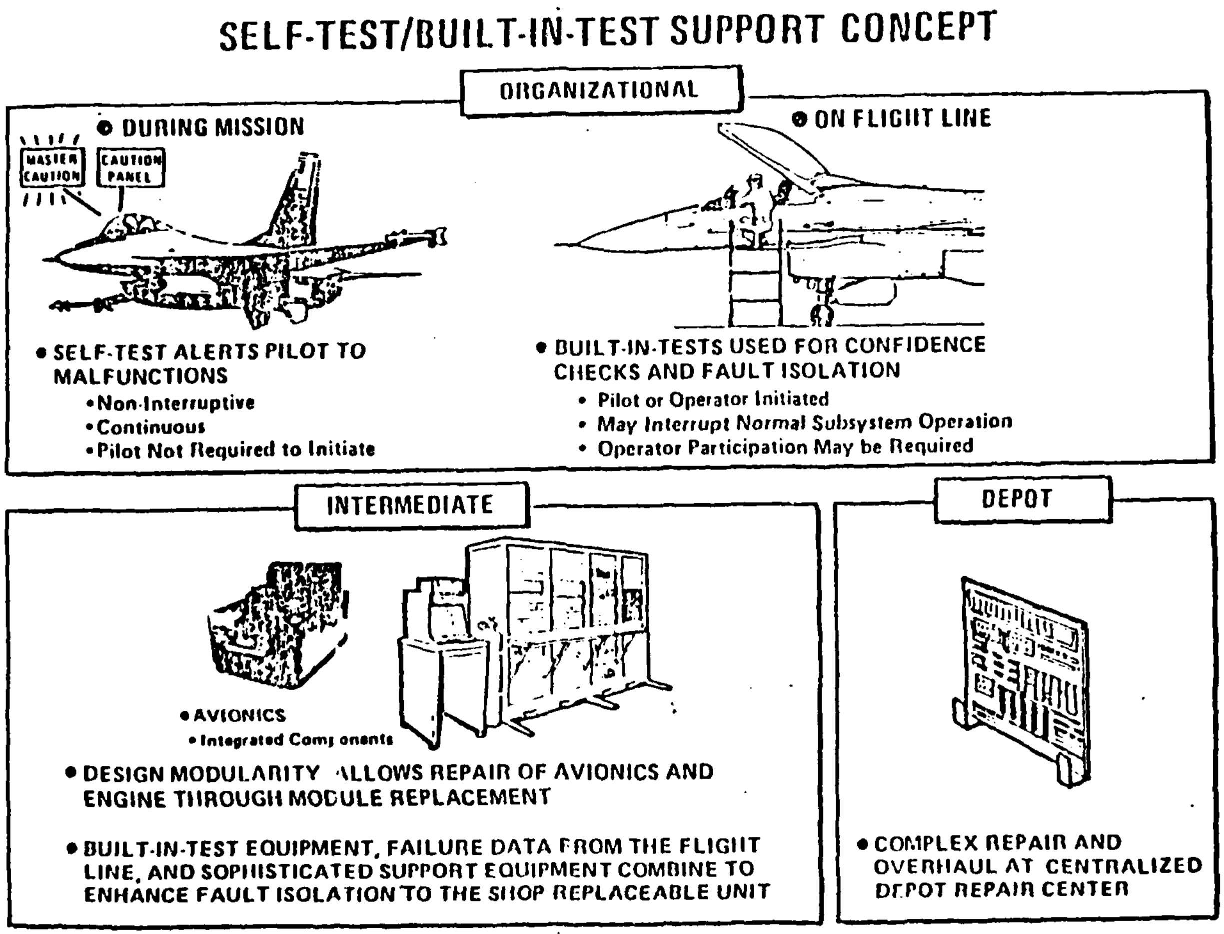


Figure 1. F-16 ST/BIT support concept.

> remove and replace aircraft equipment without the need for adjustment except as provided by BIT capability . . . minimum requirement for flightline support equipment for avionics . . . maximum use of ST/BIT for avionics system checkout and fault isolation. (Institute of Defense Analyses, 1981, p. 46)

Recent studies show diagnostic error rates anywhere from 25 to 69 percent are being experienced on the F-16 (Institute of Defense Analyses, 1981). One of the subsystems experiencing a high CND/RTOK rate (25.8 percent and 30 percent respectively) is the APG-66 Fire Control Radar built by Westinghouse Corporation (Institute of Defense Analyses, 1981; Baran, 1983).

The APG-66 is an improved programmable radar that allows the pilot to detect, track, prioritize, and engage multiple beyond-visual-range targets simultaneously. The Fire Control Radar consists of six functional Line Replaceable Units (LRUs). An LRU is defined as:

> an item that is normally removed and replaced as a single unit to correct a deficiency or malfunction on a weapon or support system. . . . any assembly which can be removed as a unit from the system at the operating location. (School of Systems and Logistics, 1981, p. 393)

The six functional LRUs are Antenna, Transmitter, Control Panel, Low Power Radio Frequency (LPRF), Digital Signal Processor, and Computer. Figure 2 depicts their pictorial representation (Morehead, Brinkman & Chambers, 1979). The LPRF has been involved in a significant number of flightline CND incidents and exhibits a high RTOK rate (approximately 45 percent) relative to other radar LRUs (Westinghouse

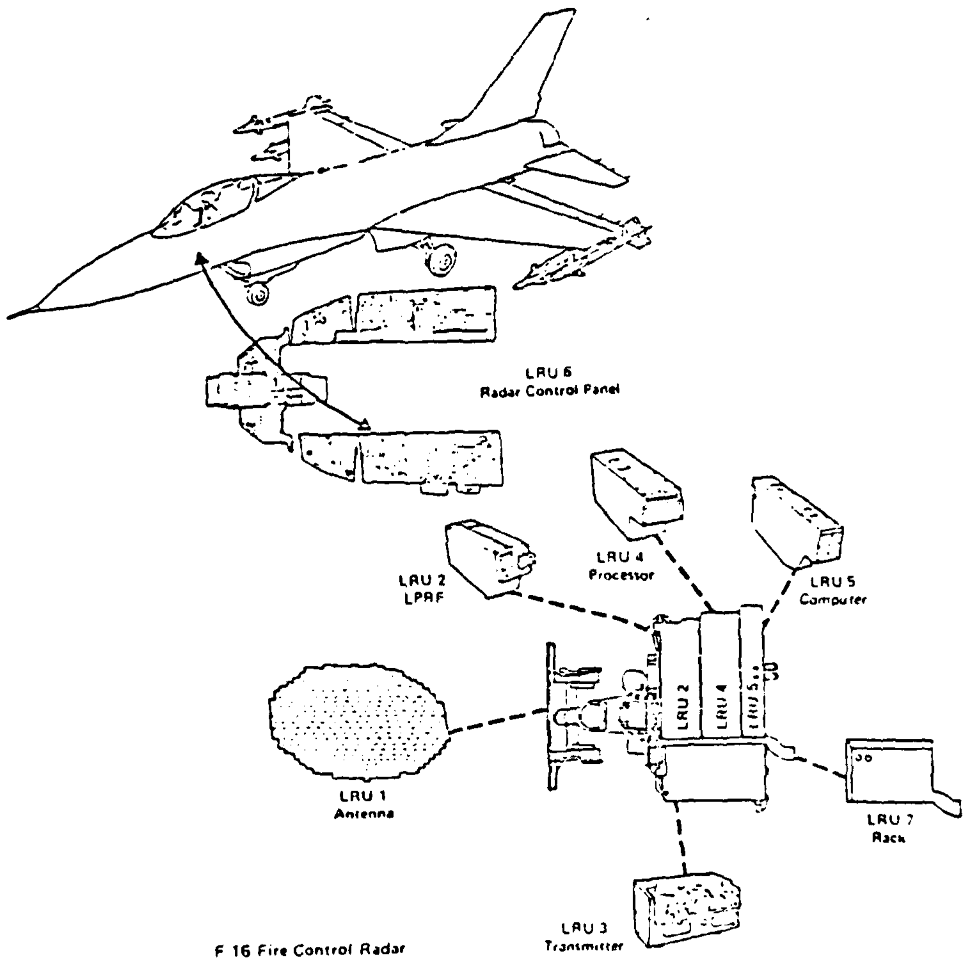


Figure 2. F-16 fire control radar.

Electric Corporation, 1983). The specific requirements of the Air Vehicle Specification (16PS002) for the F-16 state that the Fire Control Radar should detect and isolate to the LRU for 95 percent of malfunctions and that false alarms should be less than one percent (Institute of Defense Analyses, 1981).

There is a justifiable concern in the Air Force to reduce diagnostic errors on fielded systems. The costs of increased spares, aircraft turnaround delays, and overloaded intermediate shops are obvious. ST, BIT, and ATE are diagnostic aids in the process, but the decision to pull or not to pull an LRU is made by people not machines (Westinghouse Electric Corporation, 1981).

Scope of Research

Numerous weapon systems, subsystems, and components have abnormally high CND/RTOK rates. This research is limited to a specific LRU that exhibits these characteristics. The F-16 Fire Control Radar LPRF was chosen as the candidate LRU to be examined based upon its representative modern technological design, high CND/RTOK rates, and accurate, readily available maintenance data. To complement an ongoing Air Force Human Resources Laboratory (AFHRL) study, the present maintenance operations and data from the 56th Tactical Fighter Training Wing (TFTW), MacDill AFB, Florida are used as a basis for this research project.

Many quantitative techniques or models could be used to examine the maintenance process. In particular, queueing theory has been shown to be a valuable quantitative tool in the evaluation of the repair cycle for weapon systems and equipment (Anderson, Sweeney & Williams, 1982).

The F-16 repair cycle can be viewed as a waiting line problem in which LRUs fail (O-level) and subsequently arrive at the intermediate shop for service by the ATE. "Inherent in queueing theory is a system of arrivals, queues, servers, and exit from, or return to, the system" (Bryson, Husby & Webb, 1982, p. 13). The queueing model representation of this repair cycle will be presented in more detail in Chapter II.

Problem Statement

A problem exists with false removals of avionics equipment aboard the F-16 Fighting Falcon. False pulls are costly, time consuming, and ultimately lead to flight crew and maintenance technicians' complete disregard of reported malfunctions. There is a need to improve systems level test accuracy and reduce CND and RTOK rates.

Research Objective

A simulation model of the maintenance diagnostic process will be used to evaluate the impact of decision errors on F-16 aircraft availability. Evaluation will be based on sensitivity analysis of key decision variables.

The effects of improved decisions resulting in "correct" (valid and consistent) maintenance actions will be simulated by varying the CND/RTOK coefficients in the model. Thus, sensitivity analysis will determine those decision points where study in greater depth is justified and money/manpower can be saved.

Research Question #1

Can a queueing simulation model of the F-16 radar LPRF maintenance diagnostic process be developed using estimated probability distributions and descriptive parameters for test and repair times and decision point variables?

Research Question #2

Can sensitivity analysis of key decision variables be used to determine the effects of CND/RTOK rates on F-16 aircraft availability?

CHAPTER II

RESEARCH METHODOLOGY

Introduction

This thesis approaches avionics maintenance with a total system view. Although the F-16 LPRF maintenance diagnostic process is highly complex, simulation techniques will enable overall analysis of the subprocesses involved. Further analysis will provide opportunities to make tentative conclusions as to where improved diagnostic decisions or equipment capabilities are warranted.

Queueing Theory

"Quantitative models have been developed to help managers understand and make better decisions concerning the operations of waiting lines" (Anderson, Sweeney & Williams, 1982, p. 552). Therefore, describing the F-16 repair cycle with a queueing model provides for effective systems approach analysis and decision making. The required queueing scenario of arrivals, waiting lines, server stations, and exit from the system to be modeled is readily apparent in the F-16 maintenance process. Figure 3 represents this process (General Dynamics, 1975). Upon LPRF failure, a requirement exists for subsequent repair at the O and I-level maintenance subsystems. These subsystems can be viewed as processes

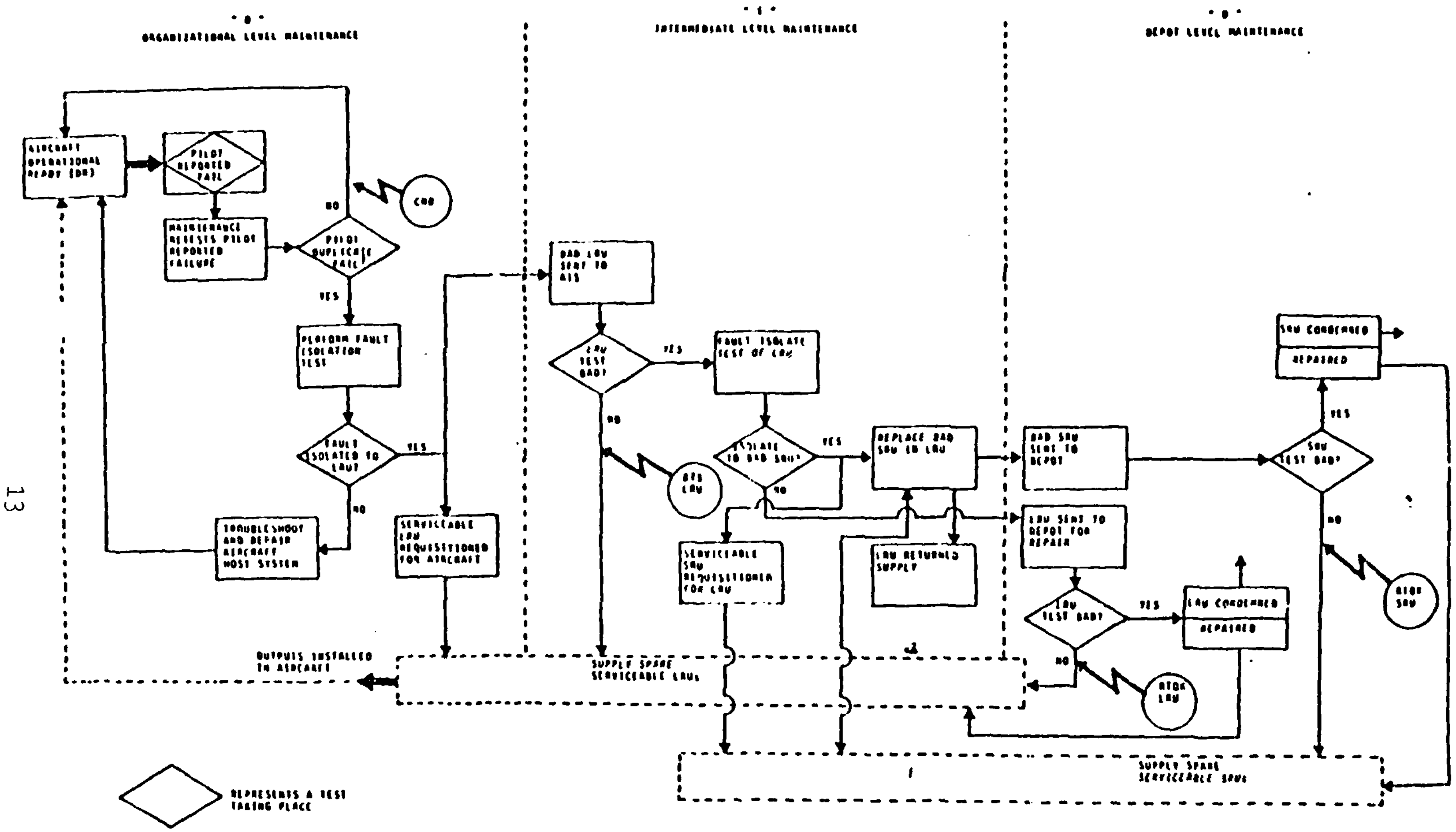


Figure 3. F-16 system maintenance repair cycle.

including waiting lines with associated servicing activities which allow return of the LPRF to a serviceable state.

Queueing theory is not only invaluable for evaluating weapon systems' repair cycles, but it also lends itself easily to further complex modeling using computer resources. Queueing-Graphical Evaluation and Review Technique (Q-GERT) is one such computerization vehicle.

Q-GERT Modeling

Q-GERT is a fairly recent computer analysis technique incorporating graphical systems modeling in a network form. Readers interested in a detailed description of Q-GERT techniques should refer to Pritsker (1979). In general, GERT is an extension of the Program Evaluation Review Technique (PERT) and the Critical Path Method (CPM) of analysis. Q-GERT networks, the graphical underpinnings of the technique, offer detailed representation of activities, servers, and queues.

> Q-GERT has been designed, developed and used for studying the procedural aspects of manufacturing, defense and service systems [emphasis added]. (Pritsker, 1979, p. vii)

The Q-GERT modeling philosophy involves a systems approach composed of four steps.

> First, a system is decomposed into its significant elements. Second, the elements are analyzed and described. Third, the elements are integrated in a network model of the system. Fourth, system performance is assessed through the evaluation of the network model. (Pritsker, 1979, p. viii)

A systems approach to modeling the F-16 LPRF repair cycle is necessary for a realistic analysis of numerous interdependent activities. Then, appropriate statistical analysis techniques can be performed to evaluate selected subsystems.

Systems Science Paradigm

To apply the systems modeling approach to an operational setting, we must employ an iterative process approach to problem solving. We will implement the Systems Science Paradigm which consolidates the systems approach for model development into three distinct phases (Schoderbek, Schoderbek & Kefalas, 1980). First, the conceptualization phase provides a clear statement of the modeled system's purpose and of the proposed problem under investigation. Next, the analysis and measurement phase involves the development of an experimental design which insures adequate analysis of simulation results and a well defined parametric model consistent with actual system data. Finally, computerization of the previously developed structural and parametric models of the system enables access to the Q-GERT program and its inherent analytical resources. Detailed accounting of these three phases is presented in Chapter III.

The Q-GERT model will require validation before we attempt any sensitivity analysis of key variables. An expanded explanation of the testing procedures for validation is presented in the Analysis of Results plan.

Data Collection Plan

Data collection will help us determine decision point coefficents and probability distributions associated with failure rates and repair times of the LPRF. Additionally, parameters for the probability distributions, such as the mean and standard deviation, will be estimated from the data. Our data collection process will include extractions of applicable items from the F-16 real time Centralized Data System (CDS). Data points not readily available in the CDS are supplemented by the F-16 Systems Program Office (SPO).

CDS Data Collection System

The F-16 CDS computer system is a real time, on-line data base designed to accommodate the data normally recorded under the manual Maintenance Data Collection system. The overall objectives of the CDS are to provide the SPO and real time users with information for the management of Avionics Intermediate Shop (AIS) test stations and selected support equipment, up-to-date and accurate F-16 related data for effective weapon system support, and a central source for maintenance data from all operational bases (Dynamics Research Corporation, 1982).

CDS provides management information on AIS usage, mean time between maintenance actions, mean time between demand, LRU status, and aircraft availability (Bryson, Husby & Webb, 1982). Thus, the CDS computer system allows for

real time accessability to F-16 operations and maintenance data and is the primary data collection source for this research.

LRU Data Collection

Through access to the F-16 SPO's CDS computer system, we will collect maintenance data on the LPRF LRU, work unit code 74ABO. CDS extractions will include frequency of maintenance actions, maintenance times for AIS testing, corresponding times to repair, and the required crew size. Our retrieval of data will include the following maintenance action taken codes--A: testing and repair, B: testing with no repair required, H: cannot duplicate malfunction, P: removal of faulty LRU, Q: installation of serviceable LRU, and R: remove and replace LRU. A major modification of the CDS on-line syntax features in January 1982 significantly improved input data accuracy (Caracillo, 1983). Therefore, data collection will cover the period from 1 February 1982 through 31 January 1983.

Data Analysis Plan

To run the Q-GERT simulation model, we must determine decision point coefficients, probability distributions, and parameters for the distributions. These input variables will be estimated with appropriate statistical techniques.

Data analysis begins with the determination of the respective decision point probabilities (coefficients) of

the maintenance diagnostic process. Data points for each action taken will be charted on a decision tree network to compute these decision point probabilities.

Our estimation of service time probability distributions requires time-to-test and time-to-repair data analysis. Data points for selected servicing actions submitted to the Statistical Package for the Social Sciences (SPSS) produce a histogram of the activity. The graphical representation is then compared against common probability distributions (i.e., normal, lognormal, exponential, etc.) for similarity. Goodness of Fit (GOF) tests confirm or reject the hypothesis that the perceived probability distribution follows the theoretically specified distribution derived from the histogram. Condescriptive statistics drawn from the histograms provide estimated means and standard deviations of the servicing distributions.

Analysis of Results Plan

We will run the model only after data analysis and estimation of probability distributions. The resultant output then requires further analysis to determine internal model validity.

> Validation is the process of building an acceptable level of confidence that the simulated data agrees with the real data closely enough that an inference about the simulation is a valid inference about the actual system. (Arnett, 1979, p. 12)

Our validation process includes internal transaction

tracing to ensure "correct" paths are being taken. Further validation of Q-GERT generated probability distributions confirms appropriate reflection of parametric data distributions. Confirmation requires application of appropriate statistical tests (histogram and goodness of fit) to the generated distributions.

The post validation process begins with an appropriate number of runs to determine model sensitivity to CND and RTOK coefficient variability. Arnett (1979) describes the "key" input variable identification technique as follows:

> By systematically varying the input variables and analyzing their effects on the output variables, the input variables with the greatest effect on output variables were identified. (p. 37)

This sensitivity analysis helps us in determining how responsive the model is to changes in input variables over an appropriate range of interest. Statistical significance of these results is tested with Analysis-of-Variance (ANOVA). One final, important question concerning overall model validity is whether or not it makes sense. Shannon's (1975) view concerning this question states that:

> The professional judgement of the people most intimately familiar with the design and operation of a system is more valuable and valid than any statistical test yet devised. (p. 236)

Model Assumptions/Limitations

The following are assumptions and limitations used in the model:

1. The AIS test stations are fully operational and allocated exclusively for the repair of the LPRF.

2. LPRF repair is considered perfect; i.e., units repaired do not exhibit subsequent, immediate failure.

3. LPRF failures are the only factors affecting aircraft operational readiness status.

4. LPRF failures and repair times are statistically independent of all other factors.

5. Servicing characteristics, such as ability, skill, and training are not considered.

6. Simulation is based upon observable factors only. (We cannot know the probability of an item passing a test when it actually has malfunctioned.)

Summary

Research Question #1

The methodology to be used to answer research question #1, determining probability distributions and parameters for test and repair times and decision point variables, will consist of (1) searching the CDS computer files to determine if such information is available, and (2) applying histograms, condescriptive statistics, and goodness of fit tests to the data (when appropriate) to estimate distributions.

Research Question #2

Research question #2 is a sensitivity analysis of certain key decision variables upon the output of the Q-GERT

model. Research question #2 asks if changes in F-16 aircraft availability occur when the CND/RTOK rates are varied. Analysis of Variance (ANOVA) tests will be used to determine if these aircraft availability results are statistically significant.

CHAPTER III

RESEARCH MODEL

Introduction

Our Q-GERT simulation model of the F-16 LPRF maintenance diagnostics process relies upon the three phases of the Systems Science Paradigm for its internal structure. Therefore, findings follow the hierarchical nature of this systems analysis. Phases of the Systems Science Paradigm are: (1) Conceptualization; (2) Analysis and Measurement; and (3) Computerization (Schoderbek, Schoderbek & Kefalas, 1980).

The first phase, conceptualization, provides a clear statement of the purpose of the system being modeled and a structural model of the proposed system's behavior. The analysis and measurement phase includes development of a parametric model and experimental design for obtaining simulation results. The final phase, computerization, links the structural and parametric models to the purpose statement. It includes a Q-GERT program listing, experimentation stages, and relevant results of the simulation output (Bobko, 1983).

Phase I: Conceptualization

This model simulates the present maintenance activities of the 56th TFTW, MacDill AFB, Florida.

Purpose Statement

Our model will simulate the arrival, waiting, testing, repairing, and return of the F-16 Fire Control Radar LPRF LRU to an operational state. The F-16 aircraft has a highly complex, multi-million dollar avionics system on board to enable the pilot to carry out his assigned mission. Because of the complex nature of this system, line maintenance personnel are not allowed to perform direct maintenance actions on the individual LRUs. They are instead removed and replaced with operable units on the flightline. This allows quick turnaround for the aircraft and reduces the required skill level of flightline personnel.

The model of the F-16 LPRF maintenance diagnostic process will be used to evaluate the impact of decision errors on aircraft availability. Evaluation of improved decisions resulting in "correct" (valid and consistent) maintenance actions will be simulated by varying the CND, RTOK, and combined CND/RTOK coefficients in the model. The model will show where increased emphasis in improved BIT and ATE capability will have the greatest benefits.

Structural Model

A structural model of the F-16 LPRF diagnostic

process may be represented with a causal loop diagram (see Figure 4). This diagram helps provide an understanding of the key component interactions and insight into the problem under analysis.

The following causal loop process explains the structural model's interactions of component relationships. The process begins when an operationally ready (OR) aircraft is written up for LPRF maintenance. This action decreases the number of OR aircraft. The aircraft LPRF write-up generates one of two possible maintenance actions. LPRF write-ups that cannot be duplicated (CND) increase the number of OR aircraft. Alternatively, an increased number of troubleshooting actions may occur.

Troubleshooting leads to the possibility of two flightline corrective actions. The first action increases the number of LPRFs removed for intermediate level maintenance when serviceable LPRFs are not immediately available. Subsequent receipt of serviceable LPRFs increases the number of installed LPRFs, which, in turn, results in increased OR aircraft. The other corrective action increases the number of immediately replaced LPRFs with a serviceable LPRF. OR aircraft are once again increased.

The unserviceable LPRFs removed at the flightline increase AIS test station use. AIS testing can be in one of three categories resulting in increased bench check and repair (BCRP), bench check no repair (RTOK), or not

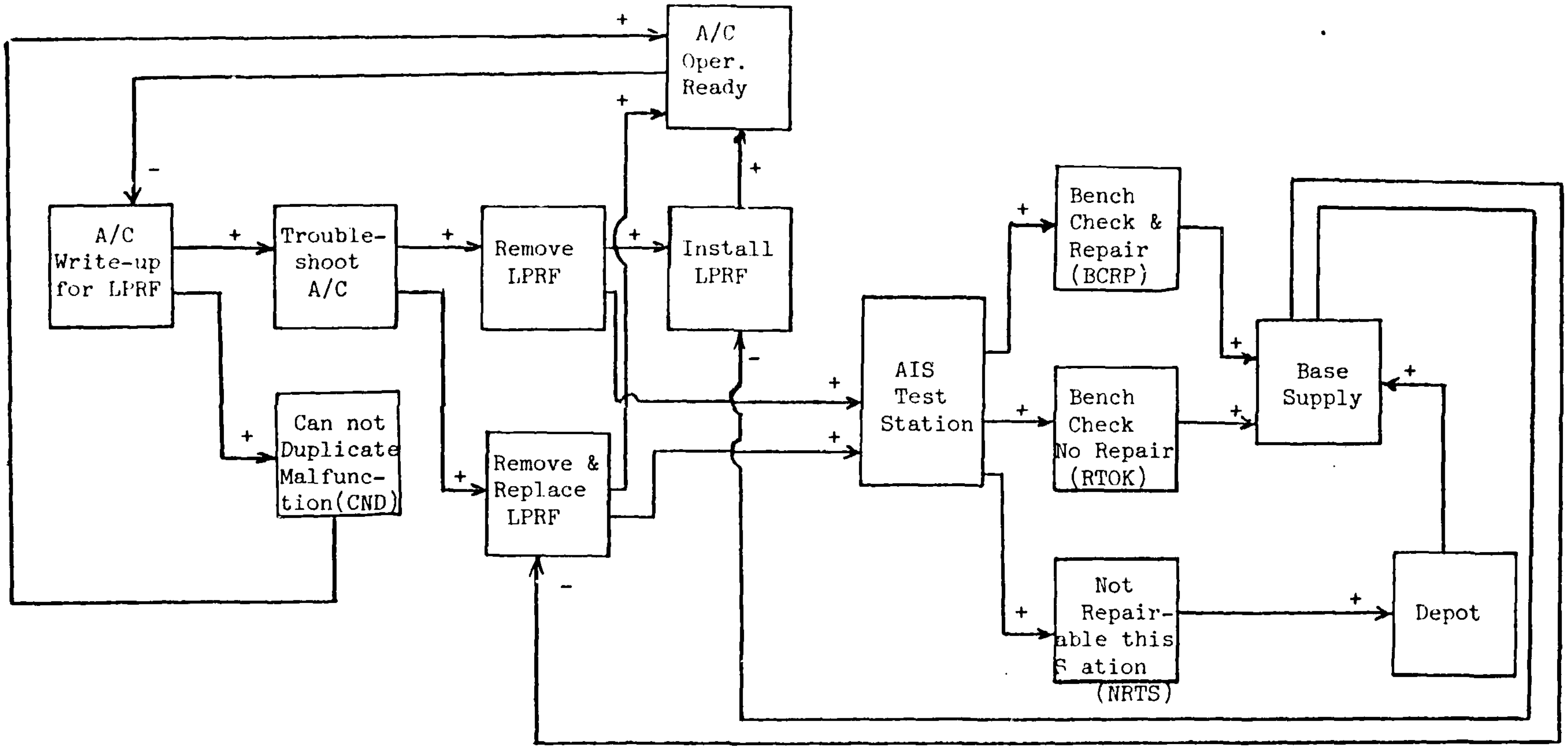


Figure 4. Causal loop diagram for F-16 maintenance diagnostic process.

repairable this station (NRTS) actions. BCRP and RTOK actions increase the number of serviceable LPRFs in Base Supply. NRTS actions increase the number of unserviceable LPRFs sent to Depot for repair. Receipt of Depot repaired LPRFs increases the number of serviceable LPRFs in Base Supply. The number of serviceable LPRFs in Base Supply decrease when fulfilling flightline maintenance action requirements.

The structural model is based upon the following assumptions:

1. Aircraft are considered operationally ready (OR) or not OR for the LPRF only. All other aircraft systems are considered OR at all times in this model.

2. The AIS test stations are fully operational and allocated exclusively for testing of the LPRF.

3. LPRF repair is considered perfect; i.e., units repaired do not exhibit subsequent, immediate failure.

4. LPRF failures and repair times are statistically independent of all other factors.

5. Servicing characteristics, such as ability, skill, and training are not considered.

6. Simulation is based on observable factors only.

7. The maintenance structure and operations at MacDill AFB, Florida are representative of the F-16 fleet in a peacetime (training) situation.

Phase II: Analysis and Measurement

Parametric Model

The structural model is used as a foundation for establishing a parametric model. Parameters and probability distributions are then estimated from existing data sources.

Data sources used were the F-16 Centralized Data System (CDS), the F-16 Systems Program Office (SPO), Headquarters (HQ) Tactical Air Command (TAC)/Avionics Division, and HQ Air Force Logistics Command (AFLC)/Analysis and Support Division. Examples of data obtained from the F-16 CDS are shown in Appendix B. The F-16 SPO, HQ TAC/Avionics, and HQ AFLC/Analysis and Support Division provided data not readily available, such as: number of test stations, number of flightline and in-shop personnel, a typical F-16 daily flying schedule, and depot repair times.

Aircraft Generation. Interarrival times of aircraft were computed using a typical flying day in a training situation. The F-16 daily flying schedule normally consists of 24 sorties. All flights are two-ship formations with an average duration of 1.0 hours (Stacey, 1983).

Table I shows the flying schedule and the computed interarrival times. These times were computed by subtracting the initial flight's landing time from the subsequent flight's arrival time. Interarrival times are presented in tenths of hours.

Table 1

Interarrival Time Data

(Mean = 0.543)

Sortie	Take-off Time	Landing Time	Interarrival Time (Tenths)
1	0800	0900	0
2	0800	0900	0
3	0810	0910	.17
4	0810	0910	.17
5	0820	0920	.17
6	0820	0920	.17
7	0830	0930	.17
8	0830	0930	.17
9	0840	0940	.17
10	0840	0940	.17
11	1100	1200	2.33
12	1100	1200	2.33
13	1110	1210	.17
14	1110	1210	.17
15	1120	1220	.17
16	1120	1220	.17
17	1130	1230	.17
18	1130	1230	.17
19	1400	1500	2.50
20	1400	1500	2.50
21	1415	1515	.25
22	1415	1515	.25
23	1430	1530	.25
24	1430	1530	.25

These 24 interarrival times were then used to obtain condescriptive statistics and histograms. A chi-square GOF test was applied and the null hypothesis that the interarrival times are exponentially distributed could not be rejected. The parameters of this distribution are a mean of 0.543 hours, a minimum of 0.0 hours, and a maximum of 2.5 hours (see Appendix C1).

Probability Distributions. The maintenance action taken data was extracted from the F-16 CDS for MacDill AFB, Florida during the period of 1 February 1982 through 31 January 1983. Work unit code 74ABO was used to specify the LPRF in this extraction process. The following maintenance action probability distribution analysis was performed.

H action takens represent the time required to CND an LPRF write-up. Our statistical analysis, which includes condescriptive statistics, a histogram, and a chi-square goodness-of-fit on the data resulted in H actions being exponentially distributed with a mean of 4.858 hours, a minimum of 1.0 hour, and a maximum of 30.0 hours (see Appendix C2).

P action takens represent the time to remove an LPRF from the aircraft. Condescriptive statistics, a histogram, and a chi-square goodness-of-fit test on the data points indicate P actions to be exponentially distributed with a mean of 4.504 hours, a minimum of 0.5 hour, and a maximum of 25.0 hours (see Appendix C3).

Q action takens represent the time to install an LPRF in the aircraft. Condescriptive statistics, a histogram, and a chi-square goodness-of-fit test resulted in Q actions being exponentially distributed with a mean of 4.45 hours, a minimum of 1.0 hour, and a maximum of 20.0 hours (see Appendix C4).

R action takens represent the time to remove and replace an LPRF on the aircraft. Condescriptive statistics, a histogram, and a chi-square goodness-of-fit test indicate that R actions are exponentially distributed with a mean of 5.115 hours, a minimum of 1.0 hour, and a maximum of 28.0 hours (see Appendix C5).

A action takens represent the time to bench check an LPRF when repair of the LPRF is required. Condescriptive statistics, a histogram, and a chi-square goodness-of-fit test resulted in A actions being exponentially distributed with a mean of 12.503 hours, a minimum of 0.4 hour, and a maximum of 101.4 hours (see Appendix C6).

B action takens represent the time to bench check an LPRF when no repair is required. This indicates a RTOK condition. Condescriptive statistics, a histogram, and a goodness-of-fit test indicate that B actions are exponentially distributed with a mean of 7.212 hours, a minimum of 1.0 hour, and a maximum of 61.0 hours (see Appendix C7).

The 1 action takens represent time to test the LPRF when repair is beyond the base capability. This is a NRTS

condition. Condescriptive statistics, a histogram, and a chi-square goodness-of-fit test resulted in 1 actions being exponentially distributed with a mean of 5.243 hours, a minimum of 0.5 hour, and a maximum of 25.7 hours (see Appendix C8).

Branching Probabilities. Q-GERT model networks rely on probabilistic branching to route transactions over alternative activity paths (Pritsker, 1979). Our model's branching coefficients were estimated from the CDS data. First, the number of actions for each maintenance code (P, R, H, B, A, and 1) were computed, followed by a ratio of the particular maintenance category to the appropriate totals. For example, of the 686 intermediate level maintenance actions (B, A, and 1), 291 were RTOK (B). This represents a .42 probability coefficient in the model. See Table II for all maintenance categories and their associated probability coefficients.

The F-16 SPO and HQ TAC/Avionics provided the following data for MacDill AFB: (1) LRU transit time from the flightline to the AIS is approximately 2.0 hours; (2) LRU transit time from the base to Depot and back for repair is approximately 48.0 hours; (3) transit time of serviceable LRUs to Base Supply is approximately 0.1 hour; (4) the number of AIS test stations assigned are 2; (5) the number of flightline maintenance personnel are 2; (6) the number of

Table 2

Branching Probabilities

Branch	Action Code		# of Actions	Probability
Troubleshoot (T-Shoot) to Removal	P		24	.17
T-Shoot to Remove and Replace (R&R)	R		116	.83
		Total	140	1.00
Flightline Action to CND	H		50	.26
Flightline Action to T-Shoot	(P, R, & L)		140	.74
		Total	190	1.00
Bench Check No Repair (RTOK)	B		291	.42
Bench Check and Repair (BCRP)	A		349	.51
Not Repairable This Station (NRTS)	1		46	.07
		Total	686	1.00

intermediate level maintenance personnel are 2; and (7) approximately 30 percent of all arriving aircraft will require maintenance action on the LPRF (Caracilla, 1983; Stacey, 1983).

Depot repair time of the F-16 radar was estimated to be lognormal with a mean of 14.0 hours and a standard deviation of 11.91 hours (Bryson, Husby & Webb, 1982). Further confirmation of this data for calendar year 1982 was through personnel at HQ AFLC/Analysis and Support Division (Newman, 1983).

Table III summarizes all the estimated parameters, probability distributions, and decision point variables represented by the F-16 LPRF maintenance diagnostic process.

The Q-GERT Model

All of the probability distributions, decision point coefficients, assumptions, and logic have now been established. A Q-GERT model can now be developed which integrates all of these factors and simulates the maintenance process. Figure 5 is an overview of the entire model using standard Q-GERT symbology. (For a complete description of Q-GERT symbology, see Appendix A.)

The model simulates the repair cycle process at MacDill AFB, Florida and the depot repair facility located at Hill AFB, Utah. For ease of explanation, the model is further sub-divided into functional areas.

Table 3

Model Parameters

Variable	Distribution/ Constant	Mean	Std Dev	Verified By
Interarrival Time	Exponential	0.543	0.858	SPSS
Prob. of Action	.30	N/A	N/A	HQ TAC/F-16 SPO
Prob. of No Action	.70	N/A	N/A	HQ TAC/F-16 SPO
Prob. of Trouble-shooting	.74	N/A	N/A	F-16 Data
Prob. of CND Action	.25	N/A	N/A	F-16 Data
CND Time	Exponential	4.858	5.099	F-16 Data/SPSS
Prob. of LPRF Removal	.17	N/A	N/A	F-16 Data
Prob. of LPRF R&R	.83	N/A	N/A	F-16 Data
Removal Time	Exponential	4.504	5.335	F-16 Data/SPSS
Installation Time	Exponential	4.450	4.823	F-16 Data/SPSS
R&R Time	Exponential	5.115	4.429	F-16 Data/SPSS
LPRF Transit Time to AIS	2.0	N/A	N/A	HQ TAC
Prob. of B/C and Repair	.51	N/A	N/A	F-16 Data

Table 3 - Continued

Variable	Distribution/ Constant	Mean	Std Dev	Verified by
Prob. of RTOK	.42	N/A	N/A	F-16 Data
Prob. of NRTS	.07	N/A	N/A	F-16 Data
B/C and Repair Time	Exponential	12.503	10.806	F-16 Data/SPSS
RTOK Time	Exponential	7.212	7.284	F-16 Data/SPSS
NRTS Time	Exponential	5.243	5.060	F-16 Data/SPSS
Depot Transit Time	48.0	N/A	N/A	HQ TAC
Depot Repair Time	Lognormal	14.0	11.91	HQ AFLC
Number of AIS	2	N/A	N/A	HQ TAC
Repaired LPRF Transit Time	0.1	N/A	N/A	HQ TAC

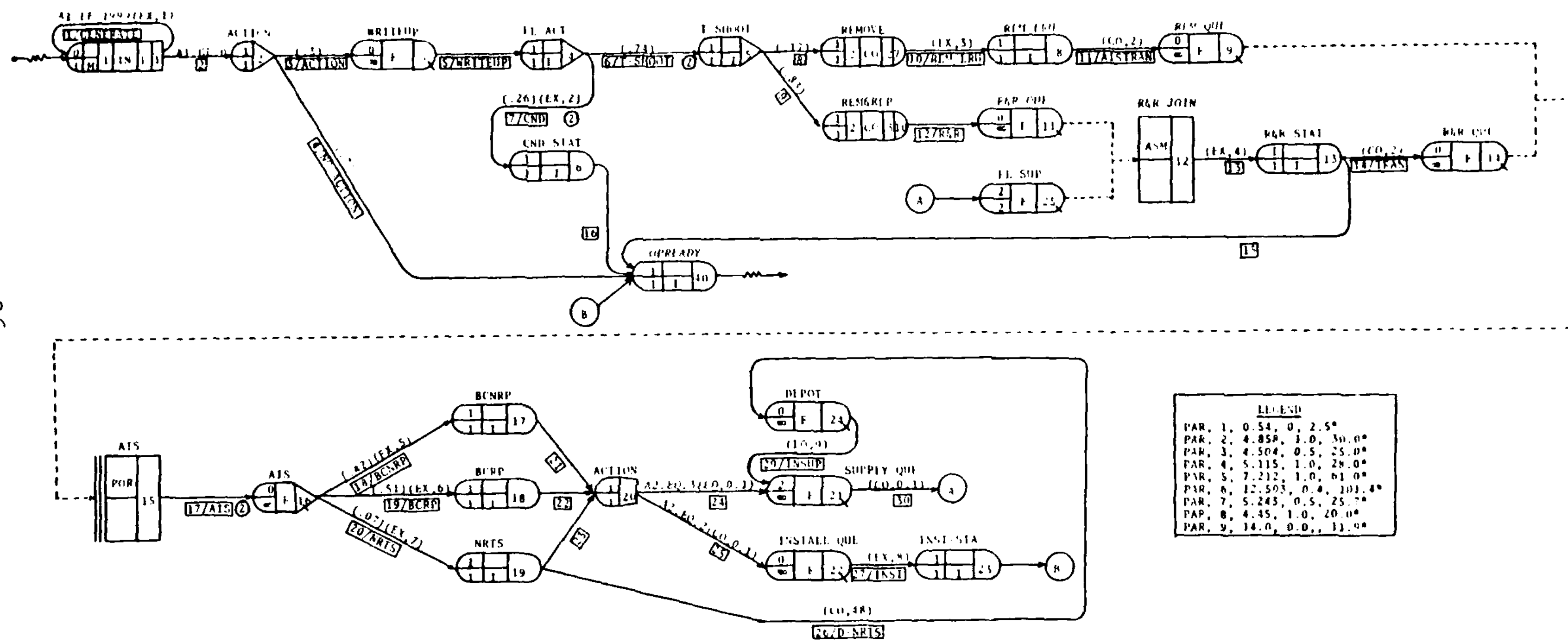


Figure 5. Q-GERT simulation model of F-16 LPRF maintenance repair process.

Figure 6 indicates the generation of aircraft arrivals for beginning the simulation. At node 1, 2000 arrivals are incremented one at a time, from an exponential distribution using parameter set 1 (see legend, Figure 5).

The arriving aircraft is then routed for action determination (see Figure 7). At node 2, the aircraft is probabilistically branched to require action on the LPRF (0.30) or so that no action is required (0.70). Aircraft requiring no action are sent to node 40, where the aircraft is considered OR for the LPRF. The aircraft requiring action travels to node 3 where it is held for flightline action.

Next, the aircraft is routed to node 4 when one of the two servers are available to perform flightline action (see Figure 8). Node 4 provides probabilistic branching for aircraft requiring troubleshooting (0.74) and LPRF action requirements which cannot be duplicated (0.26). Aircraft CND'd are sent to node 6 using an exponential distribution with parameter set 2 (see legend, Figure 5). The aircraft is then routed to node 40 where the number of OR aircraft is incremented by 1.

The aircraft requiring troubleshooting is then sent to node 5 where it is branched probabilistically for LPRF removal (0.17) or removal and immediate replacement with a serviceable LPRF (0.83)(see Figure 9).

The removed LPRF is routed to node 7 where a constant attribute value of 2 is assigned for indication of repair

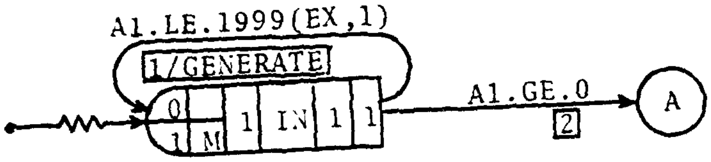


Figure 6. Interarrival of aircraft.

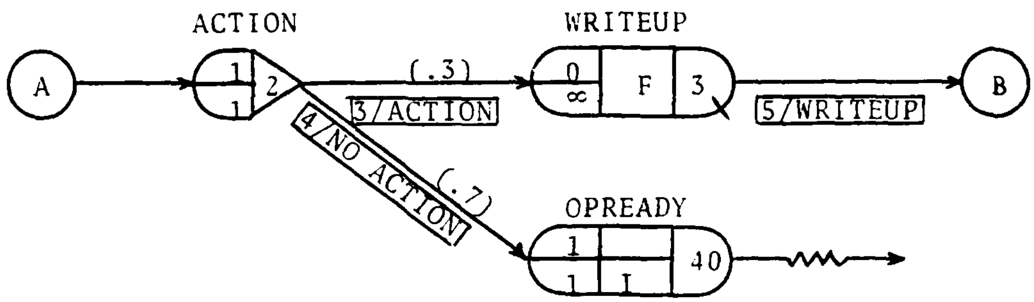


Figure 7. Action determination.

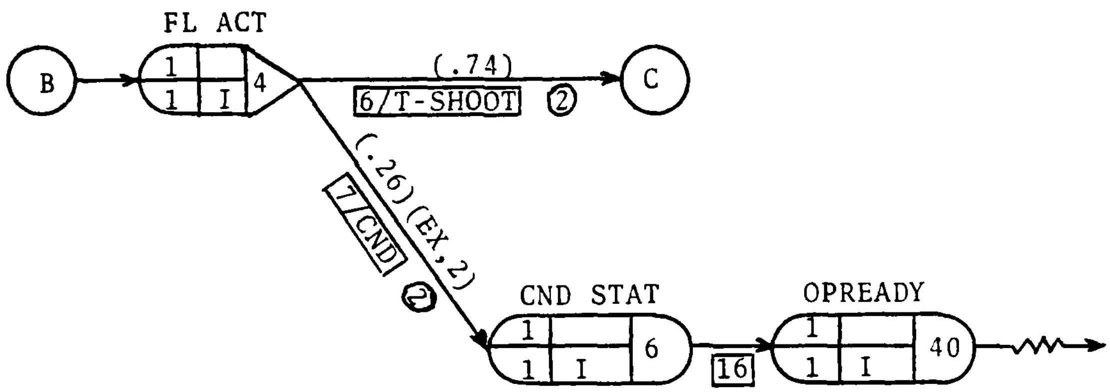


Figure 8. Flightline action determination.

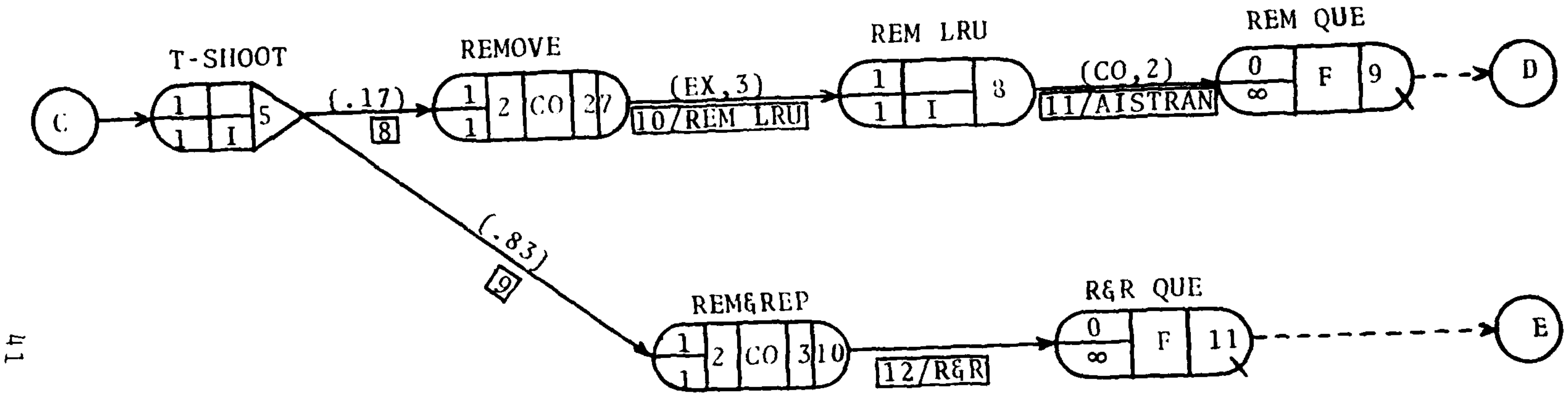


Figure 9. Flightline troubleshooting.

priority at the AIS test station and routing back for installation in the aircraft. The LPRF is then sent to node 8 using an exponential distribution with parameter set 3 (see legend, Figure 5) which simulates the time required to remove the LPRF from the aircraft. The LPRF then travels from node 8 to node 9 at a constant 2 hour rate to account for transit time of the LPRF to the AIS. Node 9 holds the removed LPRF until a station is available to repair the LPRF.

If the LPRF is to be removed and immediately replaced with a new LPRF, the aircraft is routed from node 5 to node 10 where a constant attribute value of 3 is assigned for repair prioritization. The aircraft then moves to node 11 to await a serviceable LPRF to complete the removal and replacement action.

The remove and replace action is accomplished when two conditions are satisfied (see Figure 10). First, an aircraft transaction is waiting at node 11 and secondly, a serviceable LPRF is available at node 25, the flightline supply queue. When both conditions are satisfied, selector node 12 assembles the transactions and routes them to node 13 using an exponential distribution with parameter set 4 (see legend, Figure 5). This simulates the time required to remove and replace the LPRF on the aircraft. The repaired aircraft is sent to node 40 and increments the number of OR aircraft by 1. The removed, unserviceable LPRF moves to

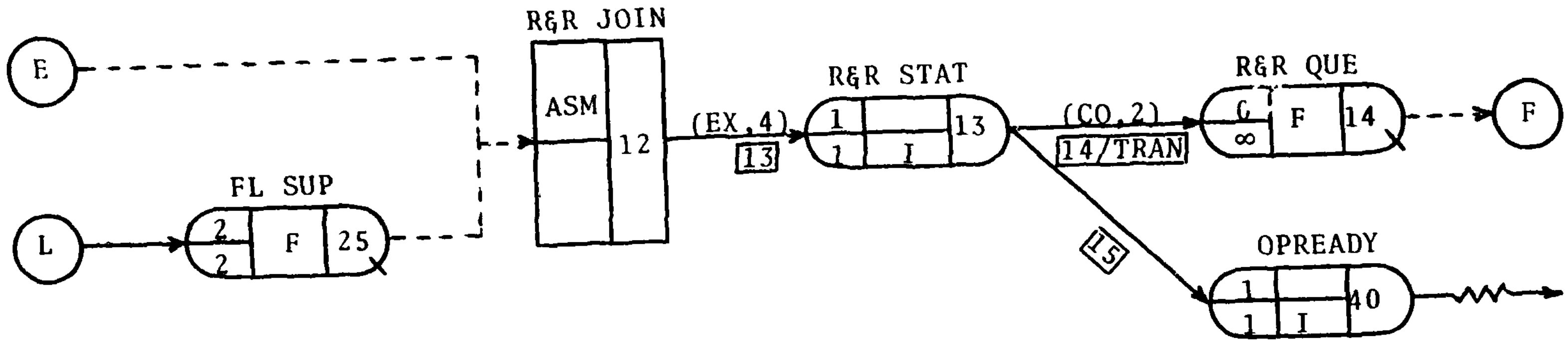


Figure 10. Remove and replace action.

node 14, where it is held awaiting an AIS test station for repair.

The blocked selection node 15 establishes a preferred order for repair of LPRFs by the two available test stations (see Figure 11). Preferred treatment is given to the removed LPRFs waiting at node 9. If no transactions are waiting at node 9, LPRFs removed during a removal and replacement action at node 14 are routed for repair when a server is available. LPRFs are sent from node 15 to node 16 for AIS repair.

LPRFs at node 16 are probabilistically branched to one of three test actions (see Figure 12). First, the LPRF might be bench checked with no repair required or RTOK (0.42). The LPRF is routed to node 17 using an exponential distribution with parameter set 5 (see legend, Figure 5). This simulates the time to bench check an LPRF with no repair. The LPRF then moves to the conditional branching node 20 for action.

Secondly, the LPRF might be bench checked and require repair (0.51). The LPRF is routed from node 16 to node 18 using an exponential distribution with parameter set 6 (see legend, Figure 5). This simulates the time to bench check and repair an LPRF. The LPRF is then sent to the conditional branching node 20 for action.

Finally, the LPRF might be tested and determined to be beyond the base's capability to repair the LPRF (0.07).

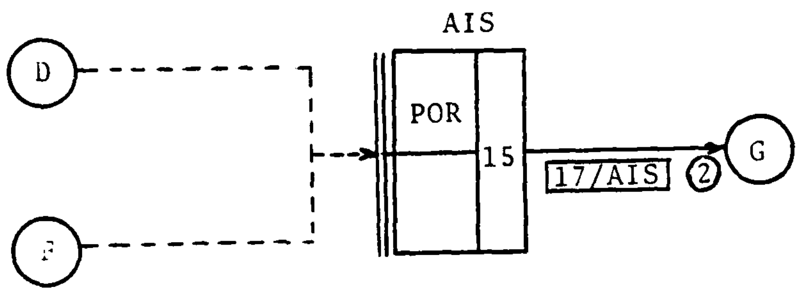


Figure 11. AIS ordering.

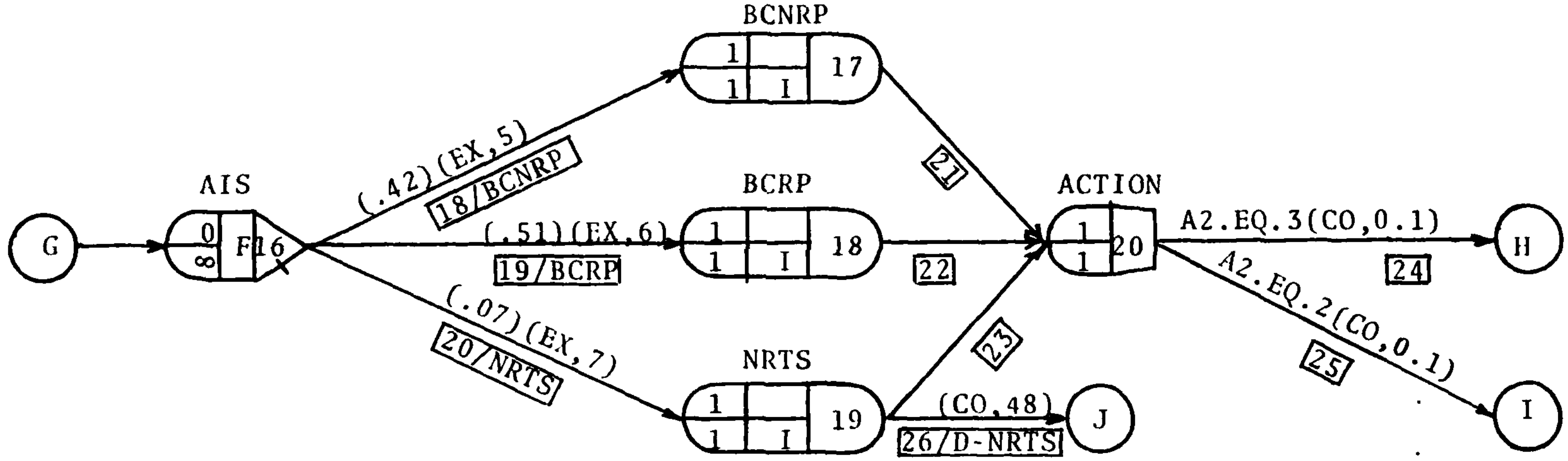


Figure 12. Intermediate shop actions.

The LPRF is routed from node 16 to node 19 for NRTS action using an exponential distribution with a parameter set 7 (see legend, Figure 5). The LPRF then moves to the conditional branching node 20 for action and to node 24, depot, at a constant of 48.0 hours for repair.

Node 20 conditionally branches the LPRF depending upon attribute value assigned during removal. LPRFs with an AT2 value of 2 are routed to node 22 for installation on an aircraft. LPRFs with an AT2 value of 3 are sent to node 21, the Base Supply queue.

LPRFs requiring installation on an aircraft are routed from node 22 to node 23 using an exponential distribution with parameter set 8 (see legend, Figure 5)(see Figure 13). This simulates the time to install an LPRF on the aircraft. The repaired aircraft moves to node 40 where the number of OR aircraft is incremented by 1.

Serviceable LPRFs are routed from depot, node 24, to node 21 using a lognormal distribution with parameter set 9 (see legend, Figure 5). This simulates the time to repair an LPRF at depot (see Figure 14). LPRFs are sent from node 21 to the flightline supply queue node 25 at a constant rate of 0.1 hours.

Experimental Design

The experimental design of a computer simulation is important for two major reasons. First, the simulation must

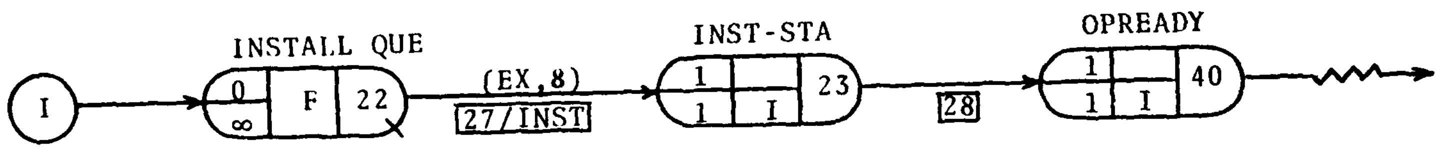


Figure 13. Installation action.

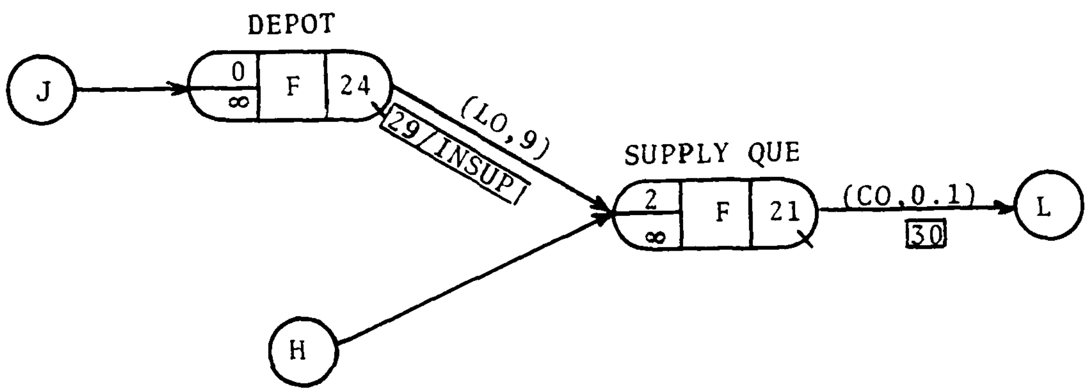


Figure 14. Supply action.

be an effective tool for learning as much as possible about the modeled system's behavioral characteristics. Second, the design must consider efficiency, as computer time is expensive. Shannon (1975, pp. 144-152) discusses the experimental design of simulations with these points in mind. We will use his suggestions in our attempt to develop an effective and efficient model.

Simulation models, in general, study the response of the dependent variable(s) as the independent variable(s) change. Our response (dependent) variable will be the time required to achieve operational readiness. Many possibilities exist in factors which might influence the response variable. Incorporating all of them into a simulation model would be impossible. According to the Pareto principle, there are a few significant factors which, in terms of performance and effectiveness, account for a large majority of the relationship (Shannon, 1975, pp. 153,154). Therefore, our simulation considers only the significant contributing factors in its design. These model variables are discussed next.

Table IV specifies the independent and dependent variables of our model. Further classification of the independent variables is by controlled, stochastic, and constant status. Controlled variables are those that are measured and varied in the experiment to determine the effect on the dependent variable. Stochastic variables vary with respect to the

Table 4

Model Variables

Independent		
Controlled	Stochastic	Constant
CND Rate	Maintenance Times	# of Technicians (Servers)
RTOK Rate	Interarrival Times	# of AIS Test Stations
CND/RTOK Rate (Combined)	Maintenance Action Probabilities	# of Spare LPRFs Transit Times
Dependent		
	Time to Aircraft Availability	

sampling distributions they are drawn from. Finally, constant variables do not vary so that experimental cause and effect relationships can be more easily determined.

In summary, our model studies the effect of varying the CND, RTOK, and combined CND/RTOK rates on the time required to achieve operational readiness. The manner in which these controlled variables were changed in the experiment is included in the sensitivity analysis section. The next consideration, efficiency of the computer simulation, begins with determination of the number of factors which will be varied in the model and at how many levels these factors will be allowed to vary. Then, the number of computer runs necessary to generate enough data for adequate analysis can be determined.

Our model examines three controlled variables which will be varied over an appropriate range of interest. Since we are concerned with the effect of increased BIT and ATE efficiency, and have determined that present capabilities are inadequate, our range of interest begins with the present base level of CND and RTOK rates. Then, these rates are reduced by one-third and two-thirds resulting in a total of three levels for each category. Therefore, our experimental design consists of three factors with three levels each. The number of computer runs is then computed using the following formula:

$$N = pq^k$$

where

k = number of factors (3)

q = number of factor levels (3)

p = number of replications (1)

N = number of computer runs required

(Shannon, 1975, p. 156)

Substituting, we arrive at the number of computer runs required to be 27.

We are confident that we have included the significant elements of the LPRF maintenance diagnostic process in our simulation model. Recognition of the experimental design criteria of effectiveness and efficiency will help in the study of this system's behavior under controlled conditions.

Phase III: Computerization

Computer Program (Q-GERT)

A computer listing of the Q-GERT program we developed from the structural and parametric models is included in Appendix D.

Model Validation

The model's validity is judged in two respects. First, we will verify the structure and logic of the model along with its internal data. We call this phase design validity. Next, the model's behavior is compared to the modeled system's actual behavior. This is generally referred to as external validity.

Design Validity. The design validity phase consists of two steps. First, internal traces of the model's transactions show that the structure and logic are sound. Transaction passages follow the incoming sortie through the model's structure and show that the sortie behaves according to plan. This internal trace allows verification of appropriate logic flow. Nodal traces reveal the times, nodes, and transaction routings taken throughout the model. An example of these traces is shown in Appendix E1. Transaction passage documentation verifies that appropriate branching probabilities are present (see Appendix E2). In the second step, the model's internal data is verified with the application of GOF tests to all Q-GERT generated probability distributions. Appendix F reflects the condescriptive data, histograms, and GOF tests for the nine Q-GERT generated distributions. These tests and associated results indicate that the Q-GERT distributions are all representative of the parametric data initially modeled.

External Validity. Confidence in our model's representativeness is based upon the valid inputs and recommendations of personnel at HQ TAC/Avionics, HQ AFLC/Analysis and Support, the F-16 SPO, and our own previous avionics maintenance experience. A telephone interview with the F-16 avionics officer at HQ TAC provided initial input for the model's structural design (Stacey, 1983). Personal interviews with the F-16 SPO Data Analysis Division Branch Chief

confirmed the appropriateness of the proposed maintenance process model (Caracillo, 1983). In addition, a personal interview with a research analyst familiar with Q-GERT modeling of the F-16 diagnostic process confirmed our model's validity (King, 1983). Shannon (1975) states:

> If the results are reasonable, if they appear to fit our previous experiences, then we tend to minimize concerns about the . . . way in which the study was conducted. On the other hand, if the results or recommendations do not make sense, all the statistical tests and analyses ever devised will not convince the decision maker to accept them. (p. 237)

We are highly confident that our model and its results "make sense" and, therefore, adequately reflect the actual F-16 radar maintenance diagnostic process.

Findings

Simulation Output

Based upon the preceding development of structural, parametric, and computerization models, the Q-GERT program was run using the baseline CND and RTOK rates. A summary of 27 observations of total time required to generate 2,000 OR aircraft is presented in Appendix G. The mean time to generate 2,000 OR aircraft in the baseline simulation was 4317.48 hours, with a standard deviation of 279.37 hours. These data points were used as a reference for the sensitivity analysis phase, discussed next.

Sensitivity Analysis

Procedure. Our previously defined range of interest

begins with the base CND and RTOK rates. We then decrease these rates (which reflect increased BIT and ATE capabilities) by one-third and then two-thirds. Corresponding to each of these reductions is a similar reduction of the maintenance action/no action branch probabilities. (As the CND or RTOK rate is decreased, the action branch is decreased due to a reduced requirement for maintenance activities.) Table V shows the model's CND and Action/No-Action coefficients at the three levels. Table VI shows the model coefficients for RTOK sensitivity analysis. Finally, Table VII shows the combined CND/RTOK model coefficients as these rates are reduced simultaneously.

Results. Table VIII is a summary of the results of our sensitivity analysis phase. (See Appendix G for a breakdown of each model run.) Initial observation of these results seems to indicate that the mean time to F-16 aircraft availability does not decrease significantly for CND reduction. However, RTOK and combined CND/RTOK reductions appear to significantly affect the time to OR. Further statistical analysis of the significance of these results is presented in the next section.

Significance Tests. Statistical significance of results will be performed in two stages. First, the applicability of parametric analysis of results is determined with the Homogeneity of Variance test. Then, an examination of

Table 5

CND Sensitivity Analysis

	CND	T-Shoot	Action	No Action
Baseline	.26	.74	.30	.70
Decrease 1/3	.19	.81	.27	.73
Decrease 2/3	.10	.90	.24	.76

Table 6

RTOK Sensitivity Analysis

	RTOK	BCRP	NRTS	Action	No Action
Baseline	.42	.51	.07	.30	.70
Decrease 1/3	.32	.59	.09	.27	.73
Decrease 2/3	.19	.71	.10	.23	.77

Table 8

Sensitivity Analysis Results

	Mean	Std Dev
	CDN Actions	
Baseline	4317.48	279.37
1/3 reduction	4257.16	274.48
2/3 reduction	4239.67	253.59
	RTOK Actions	
Baseline	4317.48	279.37
1/3 reduction	3971.50	283.96
2/3 reduction	3611.45	293.06
	Combined CND/RTOK Actions	
Baseline	4317.48	279.37
1/3 reduction	3793.28	217.87
2/3 reduction	3214.95	255.09

the difference in means via Duncan's Multiple Range and One-Way ANOVA tests provides a method of determining whether the sensitivity analysis results are significant (Bartee, 1968).

The Homogeneity of Variances tests of the response surfaces are presented in Appendices H1-H3. Results of these tests indicate equality of variance in all cases. Therefore, Duncan's Multiple Range and ANOVA tests can be used to test significance.

The Duncan procedure was applied to the CND sensitivity analysis data. The null hypothesis, which stated the means of the baseline, one-third, and two-thirds reduction in CND rate were equal, could not be rejected. The One-Way ANOVA test results were the same. Therefore, these tests confirm our initial observation that CND reductions do not significantly reduce time to aircraft OR (see Appendix H4).

RTOK sensitivity analysis data, when tested with Duncan's Multiple Range and One-Way ANOVA tests, indicates the null hypothesis of equal means can be rejected. Again, our initial suspicion that decreased RTOK rates significantly affected aircraft OR time is confirmed (for both one-third and two-thirds reductions). (See Appendix H5.)

Finally, the testing of the combined CND/RTOK sensitivity analysis data shows that the difference in means is significant for both the Duncan's and ANOVA tests. Appendix H6 displays the appropriate test and results.

Summary

This chapter showed the findings of our thesis as related to the hierarchy of the Systems Science Paradigm. First, the conceptualization phase, consisting of a clear statement of the purpose and a structural model of the system, was discussed. Second, the analysis and measurement phase related the parametric model development and the experimental design. Third, we presented the computerization phase which included the Q-GERT computer program listing, model validation, and simulation output, including sensitivity analysis. The next chapter will draw conclusions from these findings and suggest recommendations for further research.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

This study has examined the problem of increased diagnostic error rates in complex weapon systems. Specifically, the F-16 radar LPRF LRU maintenance diagnostic process was modeled using a Q-GERT simulation program. The results of this simulation as reported in Chapter III showed how CND, RTOK, and combined CND/RTOK rates affect F-16 aircraft availability. Our research questions can now be answered with regard to the simulation results.

Conclusions

Research Question #1

Can a queueing simulation model of the F-16 radar LPRF maintenance diagnostic process be developed using estimated probability distributions and descriptive parameters for test and repair times and decision point variables?

We demonstrated the potential of using the CDS for data extraction and developing probability distributions. These distributions and their descriptive parameters are described in Appendix B. Other parametric information was obtained from the F-16 SPO, HQ TAC/Avionics, and HQ AFLC. Incorporating this parametric information in a Q-GERT simulation model was accomplished successfully. The design

validity of this model shows that Q-GERT generated parameters and distributions adequately reflect the original data. Therefore, a Q-GERT model can be developed for the F-16 radar LPRF maintenance process with existing data.

Research Question #2

Can sensitivity analysis of key decision variables be used to determine the effects of CND and RTOK rates on F-16 aircraft availability?

The Duncan's Multiple Range and One-Way ANOVA tests, as reported in Appendix H, show how statistically significant are the sensitivity analysis results of CND, RTOK, and combined CND/RTOK rate variations. CND rate changes do not significantly decrease the time to aircraft OR. However, both RTOK and combined CND/RTOK rate changes are statistically significant. Sensitivity analysis of the key decision variables in our model demonstrates the effects of reduced CND, RTOK, and combined CND/RTOK rates on F-16 aircraft availability (as aircraft availability is related to time required to OR). Our conclusions with regard to this research question are that increased emphasis on improved ATE capability at the I-level or a combined improvement of BIT and ATE capabilities will reduce the time required to generate OR F-16 aircraft.

Recommendations

As a central source for data extraction and analysis

Table 7

CND/RTOK (Combined) Sensitivity Analysis

	CND	T-Shoot	RTOK	BCRP	NRTS	Action	No Action
Baseline	.26	.74	.42	.51	.07	.30	.70
Decrease 1/3	.21	.79	.32	.59	.09	.24	.76
Decrease 2/3	.14	.86	.19	.71	.10	.18	.82

the CDS is a valuable tool. The real time, on-line characteristics of this system provide logistics managers with timely knowledge of most of the maintenance information required for effective decision making. Therefore, we recommend the application of a CDS type data bank to other weapon systems. Furthermore, F-16 logistics managers should become intimately familiar with the CDS and require its inclusion in all applicable maintenance management decisions.

Regarding the results of our simulation output, we recommend additional emphasis toward improving F-16 ATE and BIT diagnostic equipment and/or procedures. Since our simulation results showed that CND reductions alone do not significantly decrease the time to aircraft OR, we recommend that emphasis be placed on improving the effectiveness of both the O-level BIT equipment and the I-level ATE. In addition to these improvements, the maintenance technician training programs should also be updated to keep up with the increased sophistication of the equipment. Obviously, the design of the new equipment and procedures should consider the available skill levels and training capabilities of O and I-level personnel.

Recommendations for Further Research

We considered the following areas during our thesis project which may require further study. Another weapon system component which exhibits high diagnostic error

characteristics could be modeled to determine the generalizability of this research project. Also, the present model, in a revised state, may be used to analyze the effects of reduced error rates on maintenance man-hours expended. Further research in all areas of maintenance diagnostics is encouraged.

Summary

In conclusion, we developed a Q-GERT simulation model through the application of the Systems Science Paradigm to the problem of increased automatic testing errors in avionics equipment. The model represented the F-16 LPRF maintenance process and attempted to discover what effect reduced CND and RTOK rates would have on F-16 aircraft availability. The computer results showed that decreased CND rates did not significantly affect the time required for aircraft OR. However, when combined with RTOK rate reductions, reduced CND rates did decrease OR time. RTOK rate reductions alone had a significant effect in reducing the time to aircraft OR. Therefore, we concluded that increased emphasis in the areas of BIT and ATE accuracy with regard to F-16 avionics is justified. Further recommendations included increased use of the CDS by logistics managers and development of a CDS type data base for other weapon systems. If the recommendations for further research are accomplished, the generalizability of this simulation project will be enhanced.

APPENDICES

APPENDIX A

ABBREVIATIONS, ACRONYMS, AND SYMBOLOGY

This appendix lists the commonly used abbreviations or acronyms involved with the logistics support of the F-16 weapon system and queueing theory terminology. Also included in this appendix is the symbology--giving the commonly used statistical symbols and the Q-GERT symbology used in the Q-GERT simulation model.

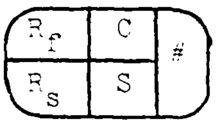
Abbreviations and Acronyms

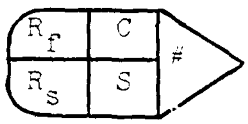
A/C	Aircraft
AFB	Air Force Base
AFHRL	Air Force Human Resources Laboratory
AFLC	Air Force Logistics Command
AIS	Automatic Intermediate Shop
ANOVA	Analysis of Variance
ATE	Automatic Test Equipment
B/C	Bench Check
BCRP	Bench Check and Repair
BIT	Built-in-Test
BITE	Built-in-Test Equipment
CDS	Centralized Data System
CND	Cannot-Duplicate
CPM	Critical Path Method
GOF	Goodness-of-Fit
HQ	Headquarters

I-LEVEL	Intermediate Level
IAT	Interarrival Time
INS	Inertial Navigation System
LPRF	Low Power Radio Frequency
LRU	Line Replaceable Unit
NRTS	Not Repairable This Station
O-LEVEL	Organizational Level
OR	Operationally Ready
PERT	Program Evaluation Review Technique
PROB	Probability
Q-GERT	Queueing-Graphical Evaluation and Review Technique
R&R	Remove and Replace
RADC	Rome Air Development Center
RTOK	Retest-OK/Bench Check-No Repair Required
SPO	Systems Program Office
SPSS	Statistical Package for the Social Sciences
ST	Self Test
T-Shoot	Troubleshoot
TAC	Tactical Air Command
TFTW	Tactical Fighter Training Wing

Symbols

H_a	Alternative Hypothesis
H_o	Null Hypothesis
n	Number of Cases
α	Alpha Value
>	Greater Than
<	Less Than





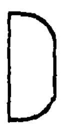
R_f is the number of incoming transactions required to release the node for the first time.

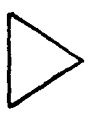
R_s is the number of incoming transactions required to release the node for all subsequent times.

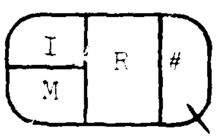
C is the criterion for holding the attribute set at a node.

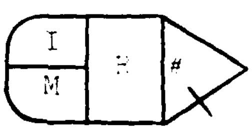
S is the statistics collection type or marking.

is the node number.


indicates deterministic branching from the node.


indicates probabilistic branching from the node.





I is the initial number of transactions at the Q-node.

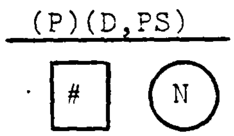
M is the maximum number of transactions permitted at the Q-node.

R is the ranking procedure for ordering transactions at the Q-node.

is the Q-node number.

Symbols - Continued

Pointer to a source node or from a sink node.



P is the probability of taking the activity (only used if probabilistic branching from the start node of the activity is specified).

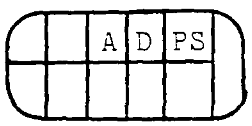
D is the distribution or function type from which the activity time is to be determined.

PS is the parameter set number (or constant value) where the parameters for the activity time are specified.

\# is the activity number

N is the number of parallel servers associated with the activity (only used if the start node of the activity is a Q-node).

Concept: Value Assignment

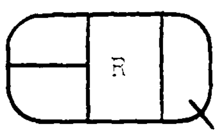


A is the attribute number to which a value is to be assigned; if A+ is specified, add value to attribute A; if A- is specified, subtract value from attribute A.

D is the distribution or function type from which assignment value is to be determined.

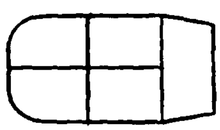
PS is the parameter set number.

Concept: Queue Ranking



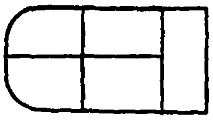
R is the ranking procedure for ordering transactions at the Q-node. R can be specified as: F → FIFO; L → LIFO; B/i → Big value of attribute i; S/i → Small value of attribute i. If i = M, ranking is based on mark time.

Concept: Conditional, Take-First Branching



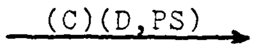
 indicates conditional-take first branching from the node.

Symbols - Continued



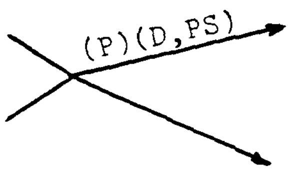
Concept: Conditional, Take-all Branching

 indicates conditional-take all branching from the node.



Concept: Condition Specification for Branch

C is the condition specification for taking the activity.

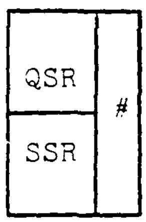


Concept: Attribute Based Probabilistic Branching

If P<1.0, P is the probability of taking the activity.

If P≧1, P is an attribute number.

Concept: Selector node or S-node



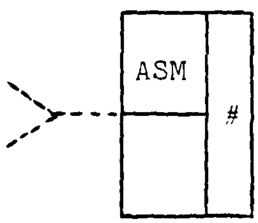
QSR is the queue selection rule for routing transactions to or from Q-nodes.

SSR is the server selection rule for deciding which server to make busy if a choice exists.

is the S-node number.

Concept: Routing Indicator

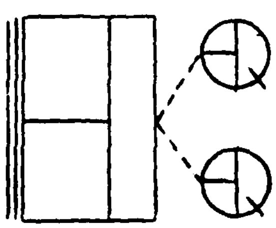
Routing indicator for transaction flow to or from Q-nodes to S-nodes or Match nodes.



Concept: Assembly by S-nodes

ASM is the queue selection rule that requires transactions to be assembled from two or more queues.

Concept: Blocking



Blocking at an S-node.

APPENDIX B

F-16 CENTRALIZED DATA SYSTEM (CDS) MAINTENANCE DATA

Appendix B, F-16 Centralized Data System (CDS) Maintenance Data, contains direct output for 74ABO, Low Power Radio Frequency (LPRF) Line Replaceable Unit (LRU) including: column one--the Job Control number; column two--the action taken code; column three--the maintenance action start time; column four--the maintenance action stop time; and column five--the number of personnel (crew) performing the maintenance action. A total of 686 maintenance action data points were used to develop parameters and probability distributions. Examples of each type of actions are presented.

JCN	ACTION TAKEN	START TIME	END TIME	CREW SIZE
0044201	H	0920	1040	2
00708R3	H	1930	2230	2
01108A3	H	2100	2230	2
0244305	H	1600	1700	3
0493906	H	1900	2400	2
0534005	H	1600	1900	2
0614202	H	1600	1630	2
0040674	P	1700	1800	2
0274389	P	1000	1100	2
0483908	P	2100	2200	2
0753905	P	1300	1400	2
0913900	P	1400	1430	3
1234201	P	0800	1000	3

JCN	ACTION TAKEN	START TIME	END TIME	CREW SIZE
0040674	Q	0800	0900	2
0274389	Q	1300	1400	2
0483908	Q	1900	2000	2
0753905	Q	1000	1200	3
0913900	Q	2100	2200	2
1234201	Q	1700	1900	3
0033607	R	2100	2330	2
0044004	R	0700	0900	2
0113801	R	1600	1700	2
0203920	R	1600	1730	1
0403887	R	2100	2300	2
0524001	R	1800	2000	2
0614011	R	1600	1800	2
0030007	A	1630	1830	1
0039636	A	2355	0500	1
0040822	A	1000	1515	2
0044004	A	1600	1700	2
0047428	A	1530	1630	2
0070011	A	1630	2030	1
0073001	A	1000	1400	2
0014975	B	1715	1900	1
0020101	B	2015	2245	1
0030015	B	1810	2015	1
0031403	B	1700	2100	1
0040013	B	1000	1700	2
0040019	B	0800	1400	1
0040022	B	1245	1450	2

JCN	ACTION TAKEN	START TIME	END TIME	CREW SIZE
0042850	1	0300	0700	2
0066527	1	1400	1430	2
0176814	1	1400	1545	3
0396203	1	0700	0930	3
0496203	1	1700	1730	3
0500660	1	0700	0900	2
0554205	1	2400	0300	2

APPENDIX C

CONDESCRIPTIVE STATISTICS, HISTOGRAMS, AND
GOODNESS-OF-FIT TESTS

Appendix C is divided into eight parts. Appendix C1 is computer-generated condescriptive statistics, histogram, and goodness-of-fit test of the interarrival time data of Table I. Appendix C2 through C8 are computer-generated condescriptive statistics, histograms, and goodness-of-fit tests of the test times as shown in Table 3.

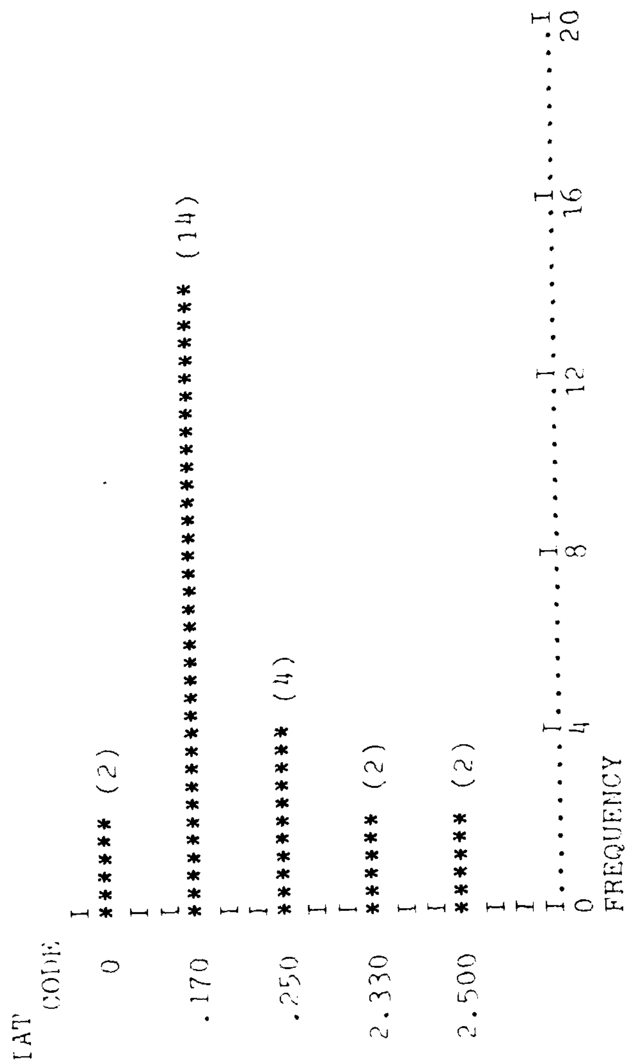
APPENDIX C1

INTERARRIVAL TIME CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TEST

VARIABLE IAT

MEAN	.543	STD ERR	.175	STD DEV	.858
VARIANCE	.736	SKEWNESS	1.896	KURTOSIS	1.795
MINIMUM	0.	MAXIMUM	2.500	SUM	13.040

VALID OBSERVATIONS - 24



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
24	4.125	.042

H_o: Interarrival times of aircraft are exponentially distributed.

H_a: Interarrival times of aircraft are not exponentially distributed.

Since .042 (significance) > .01 alpha value, the null hypothesis that the interarrival times of aircraft are exponentially distributed cannot be rejected.

AD-A134 280 A Q-GERT ANALYSIS OF THE EFFECT OF IMPROVED AUTOMATIC TESTING ON F-16 AIR..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST..

2/2

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DATE
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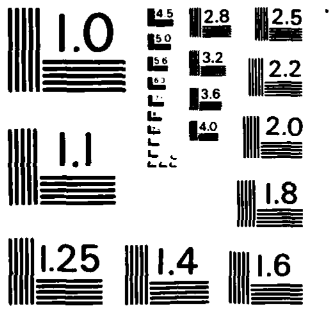


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX C2

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TESTS FOR THE TIME-TO-CND RANDOM VARIABLE

```
VARIABLE      CND

MEAN            4.858    STD ERR          .721    STD DEV        5.099
VARIANCE       25.997    SKEWNESS        3.238    KURTOSIS      12.729
MINIMUM         1.000    MAXIMUM        30.000    SUM          242.900

VALID OBSERVATIONS -  50
```

```
CND
 CODE
          I
  2.000   ***************************  (26)
          I
          I
  5.000   ****************  (15)
          I
          I
  8.000   *****  (4)
          I
          I
 11.000   ***  (2)
          I
          I
 14.000   **  (1)
          I
          I
 20.000   **  (1)
          I
          I
 29.000   **  (1)
          I
          I
          I.........I.........I.........I.........I.........I
          0        10        20        30        40        50
          FREQUENCY
```

CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
50	1.712	.788

H_o: Time-to-CND LRPF write-ups are exponentially distributed.

H_a: Time-to-CND LPRF write-ups are not exponentially distributed.

Since .788 (significance) > .01 alpha value, the null hypothesis that the time-to-CND LPRF write-ups are exponentially distributed cannot be rejected.

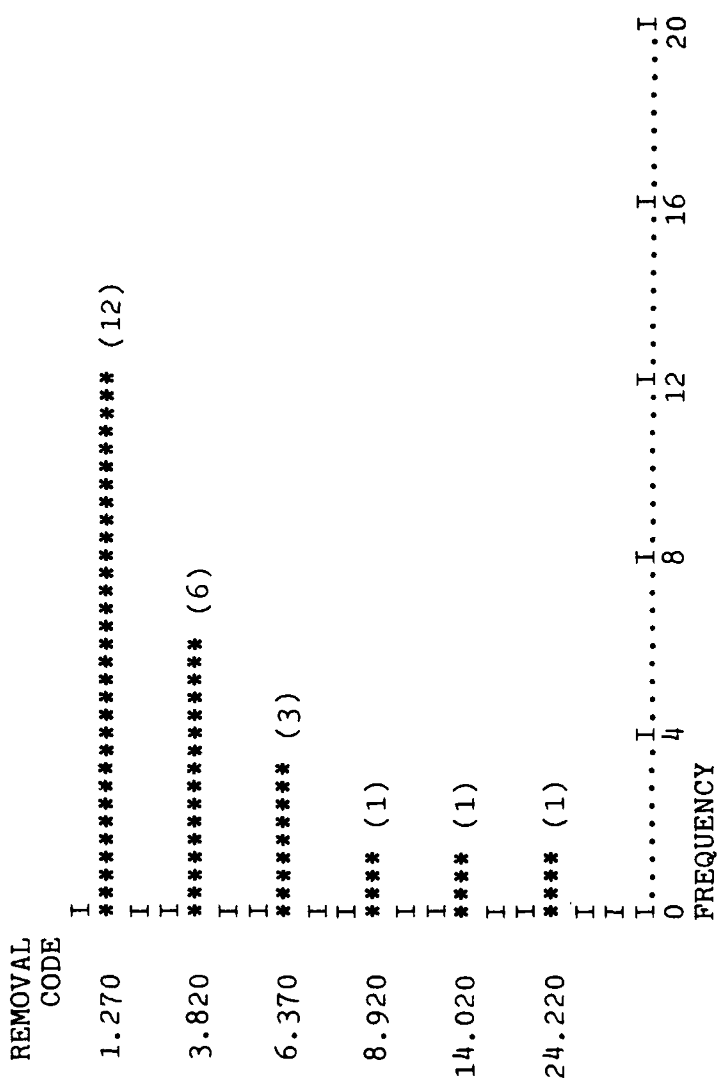
APPENDIX C3

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TESTS FOR THE TIME-TO-REMOVE RANDOM VARIABLE

VARIABLE REMOVAL

MEAN	4.504	STD ERR	1.089	STD DEV	5.335
VARIANCE	28.461	SKEWNESS	2.970	KURTOSIS	9.791
MINIMUM	.500	MAXIMUM	25.000	SUM	108.100

VALID OBSERVATIONS - 24



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
24	.407	.816

H_o: Time-to-remove LPRFs are exponentially distributed.

H_a: Time-to-remove LPRFs are not exponentially distributed.

Since .816 (significance) > .01 alpha value, the null hypothesis that time-to-remove LPRFs are exponentially distributed cannot be rejected.

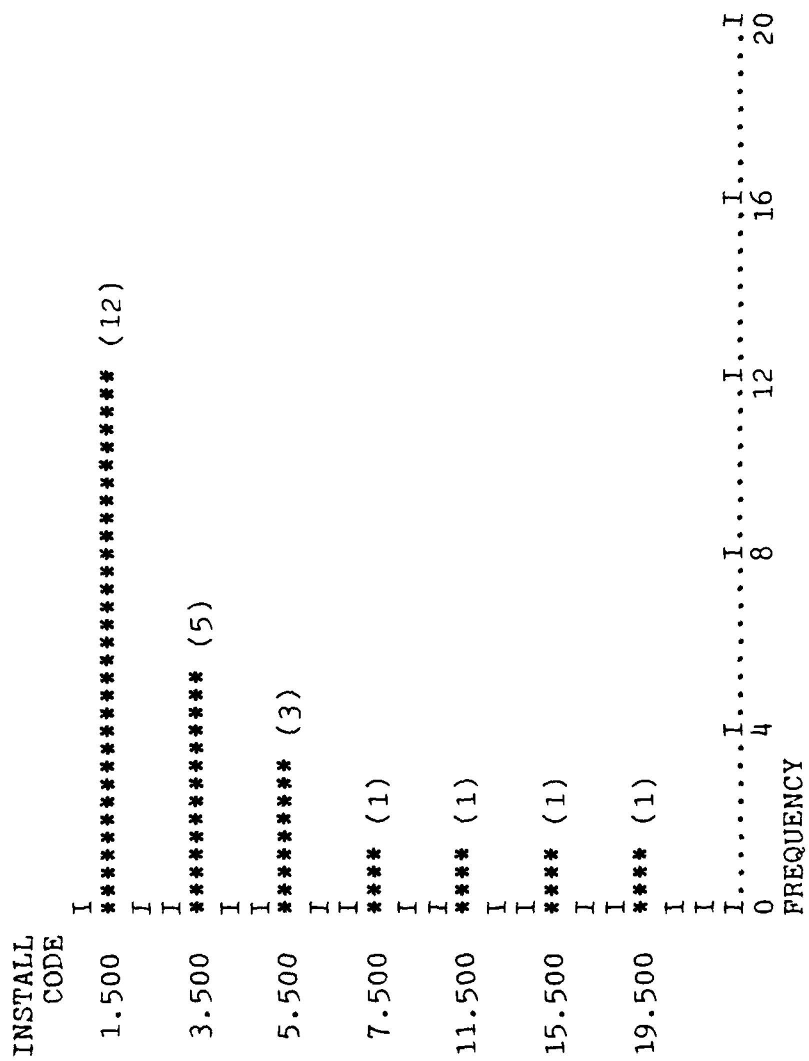
APPENDIX C4

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TESTS FOR THE TIME-TO-INSTALL RANDOM VARIABLE

VARIABLE INSTALL

MEAN	4.450	STD ERR	.984	STD DEV	4.823
VARIANCE	23.260	SKEWNESS	4.410	KURTOSIS	4.410
MINIMUM.	1.000	MAXIMUM	20.000	SUM	106.800

VALID OBSERVATIONS - 24



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
24	.012	.994

H_o: Time-to-install LPRFs are exponentially distributed.

H_a: Time-to-install LRPFs are not exponentially distributed.

Since .994 (significance) > .01 alpha value, the null hypothesis that time-to-install LPRFs are exponentially distributed cannot be rejected.

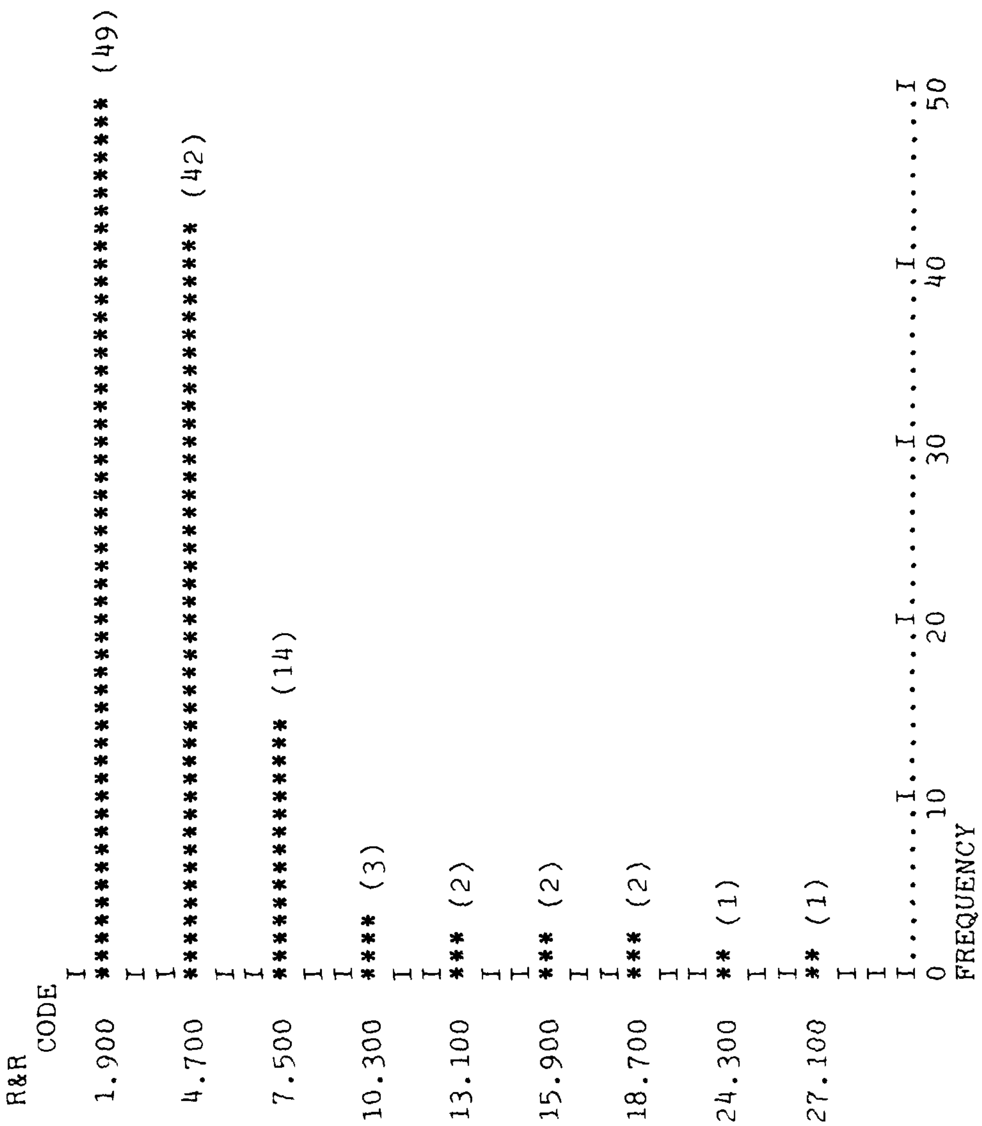
APPENDIX C5

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TESTS FOR THE TIME-TO-REMOVE AND REPLACE RANDOM VARIABLE

VARIABLE R&R

MEAN	5.115	STD ERR	.411	STD DEV	4.429
VARIANCE	19.615	SKEWNESS	2.854	KURTOSIS	9.734
MINIMUM	1.000	MAXIMUM	28.000	SUM	593.300

VALID OBSERVATIONS - 116



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
116	10.623	.059

H_o: Time-to-remove and replace LPRFs are exponentially distributed.

H_a: Time-to-remove and replace LPRFs are not exponentially distributed.

Since .059 (significance) > .01 alpha value, the null hypothesis that time-to-remove and replace LPRFs are exponentially distributed cannot be rejected.

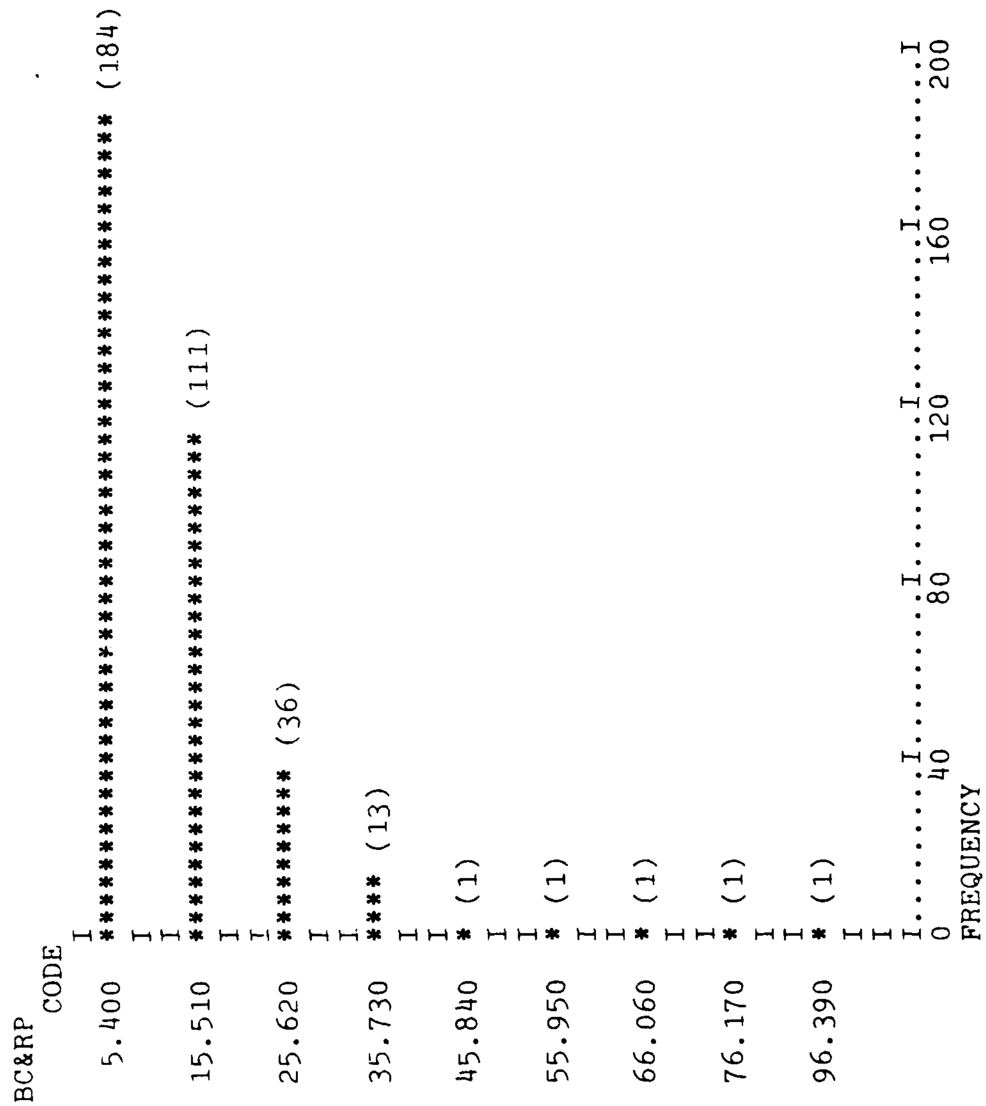
APPENDIX C6

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TESTS FOR TIME-TO-BENCH CHECK AND REPAIR RANDOM VARIABLE

VARIABLE BC&RP

MEAN	12.503	STD ERR	.578	STD DEV	10.806
VARIANCE	116.774	SKEWNESS	3.108	KURTOSIS	17.382
MINIMUM	.400	MAXIMUM	101.400	SUM	4363.450

VALID OBSERVATIONS - 349



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
349	9.898	.019

H_o: Time-to-bench check and repair LPRFs are exponentially distributed.

H_a: Time-to-bench check and repair LPRFs are not exponentially distributed.

Since .019 (significance) > .01 alpha value, the null hypothesis that time-to-bench check and repair LRPFs are exponentially distributed cannot be rejected.

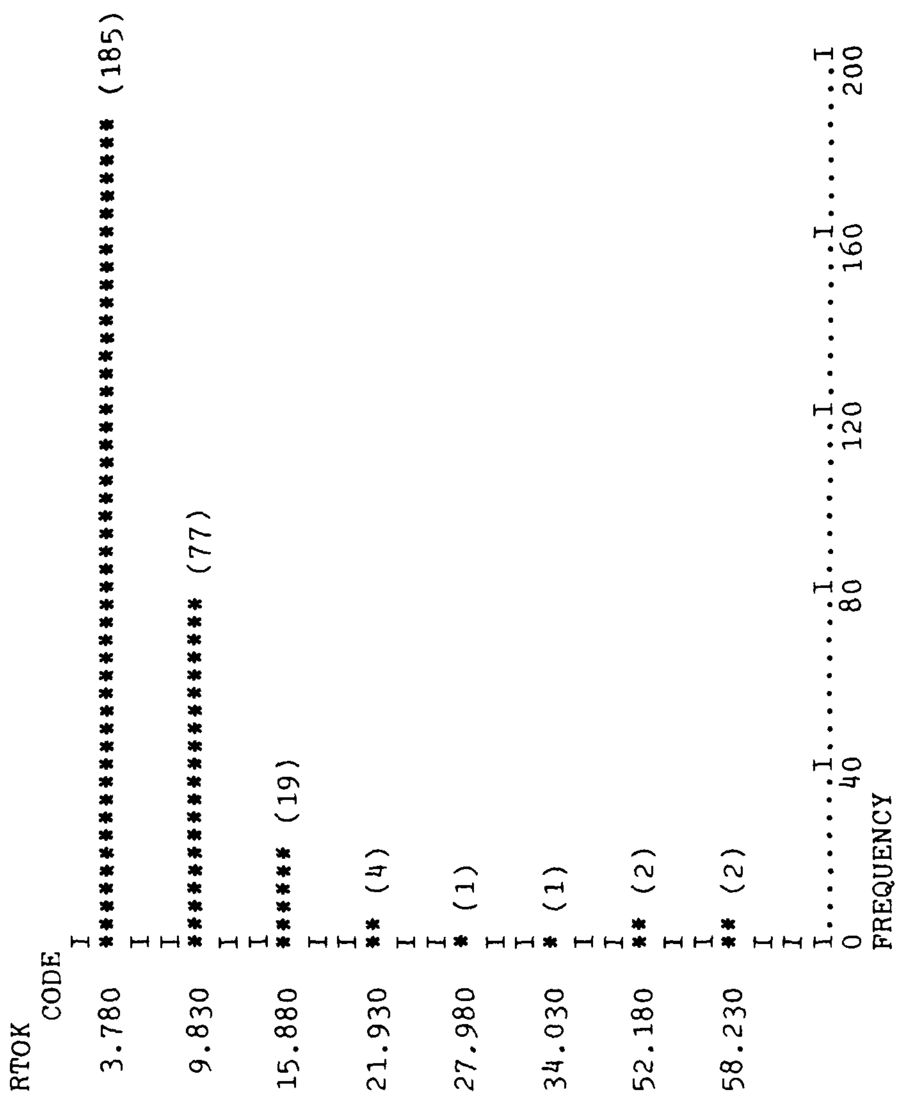
APPENDIX C7

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TESTS FOR TIME-TO-BENCH CHECK WITH NO REPAIR (RTOK) RANDOM VARIABLE

VARIABLE RTOK

MEAN	7.212	STD ERR	.427	STD DEV	7.284
VARIANCE	53.050	SKEWNESS	4.641	KURTOSIS	27.866
MINIMUM	*1.000*	*MAXIMUM*	*61.000*	*SUM*	*2089.700*

VALID OBSERVATIONS - 291



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
291	1.942	.584

H_o: Time-to-bench check LPRFs with no repair required are exponentially distributed.

H_a: Time-to-bench check LPRFs with no repair required are not exponentially distributed.

Since .584 (significance) > .01 alpha value, the null hypothesis that time-to-bench check LPRFs with no repair required are exponentially distributed cannot be rejected.

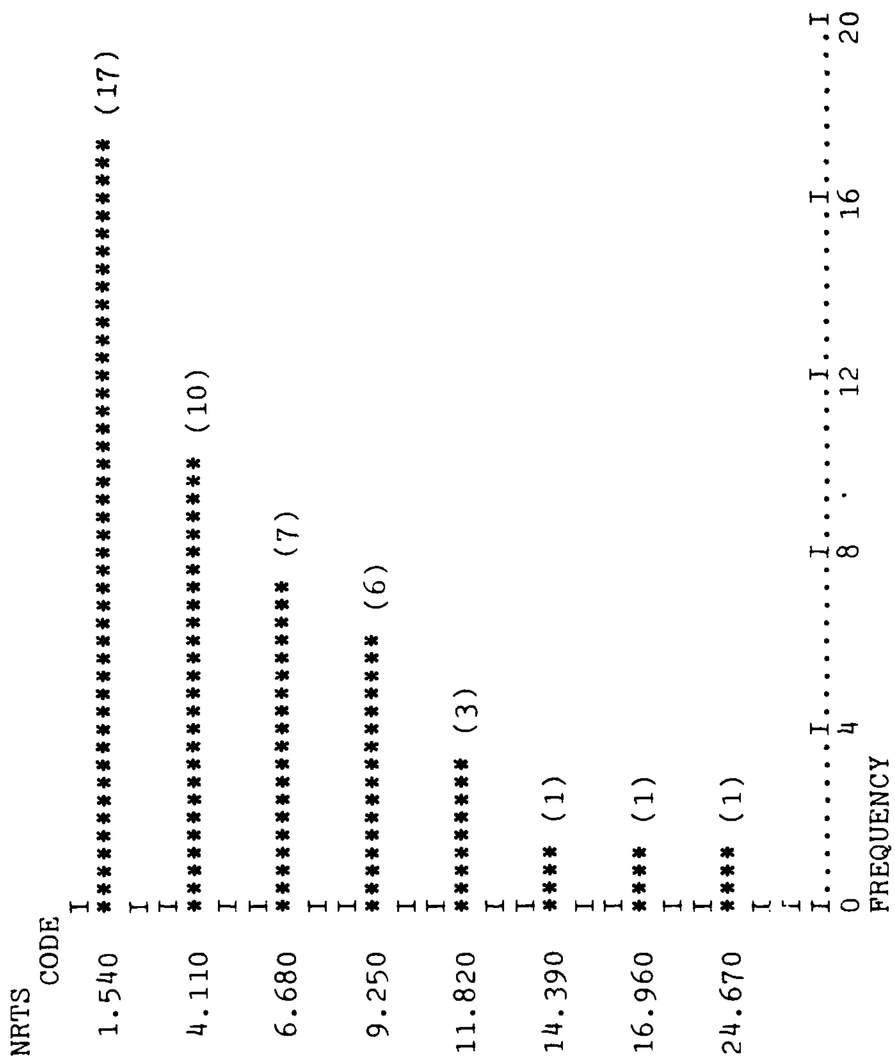
APPENDIX C8

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TESTS FOR TIME-TO-NRTS RANDOM VARIABLE

VARIABLE NRTS

MEAN	5.243	STD ERR	.746	STD DEV	5.060
VARIANCE	25.607	SKEWNESS	1.892	KURTOSIS	4.840
MINIMUM	.500	MAXIMUM	25.700	SUM	241.200

VALID OBSERVATIONS - 46



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
46	1.680	.794

H_o: Time-to-test LPRFs when repair is beyond the base's capability are exponentially distributed.

H_a: Time-to-test LPRFs when repair is beyond the base's capability are not exponentially distributed.

Since .794 (significance) > .01 alpha value, the null hypothesis that time-to-test LPRFs when repair is beyond the base's capability are exponentially distributed cannot be rejected.

APPENDIX D

Q-GERT SIMULATION MODEL PROGRAM

Appendix D, Q-GERT Simulation Model Program, contains the computer input to run the Q-GERT simulation program.

```
*** INPUT CARDS ***

GEN,BENONE,THESIS,09,28,1983,9,1,2000,6000,27,E,(14)2*
SOU,1,0,1,A*                    GENERATE ARRIVALS
VAS,1,1,IN,1*                   INCREMENT ARRIVALS
REG,2/ACTION,1,1,P*             DETERMINE WRITE-UP ACTION
QUE,3/WRITEUP,,,D,F*            AIRCRAFT HAS A WRITE-UP
STA,4/FL ACT,1,1,P,I*           DECIDE FLIGHTLINE ACTION
STA,5/T-SHOOT,1,1,P,I*          WRITE-UP IS TROUBLESHOT
STA,6/CND STAT,1,1,D,I*         WRITE-UP IS A CND
REG,7/REMOVE,1,1,D*             REMOVE ACTION
VAS,7,2,CO,2*                   ASSIGN A REMOVE ATTRIBUTE
STA,8/REM LRU,1,1,D,I*          TRANSPORT REMOVED LRU
QUE,9/REM QUE,0,,D,F,(10)15*    HOLD REMOVED LRU FOR AIS
REG,10/REM&REP,1,1,D*           REMOVE AND REPLACE ACTION
VAS,10,2,CO,3*                  ASSIGN REMOVE AND REPLACE ATTRIBUTE
QUE,11/R&R QUE,0,,D,F,(10)12*   HOLD R&R LRU FOR ASSEMBLY
SEL,12/R&R JOIN,ASM,(7)25,11*   ASSY OF R&R ACTIONS AND UNITS
STA,13/R&R STAT,1,1,D,I*        REMOVE AND REPLACE STATISTICS
QUE,14/R&R QUE,,,D,F,(10)15*    HOLD REMOVE AND REPLACE LRU FOR ACTION
SEL,15/AIS,POR,(6)B,9,14*       AIS TEST STATION
QUE,16/AIS ACT,0,,P,F*          DETERMINE TEST ACTION
STA,17/BCNRP,1,1,D,I*           BENCH CHECK NO REPAIR (RTOK)
STA,18/BCRP,1,1,D,I*            BENCH CHECK AND REPAIR
STA,19/NRTS,1,1,D,I*            NOT REPAIRABLE THIS STATION (NRTS)
REG,20/REPAIR,1,1,F*            ROUTE REPAIRED UNIT
QUE,21/SUPPLY,2,,D,F,24*        BASE SUPPLY
QUE,22/INSTALL,,,D,F*           HOLD FOR INSTALLATION ACTION
STA,23/INST-STA,1,1,D,I*        INSTALLATION STATISTICS
QUE,24/DEPOT,,,D,F*             DEPOT
QUE,25/FL SUP,2,2,D,F,(10)12*   FLIGHTLINE SUPPLY QUE
SIN,40/OPREADY,1,1,D,I*         OPERATIONAL READY SINK
ACT,1,1,EX,1,1,/GENERATE,(9)A1.LE.1999*
PAR,1,0.54,0,2.5*
ACT,1,2,,,2,(9)A1.GE.0*
ACT,2,3,,,3/ACTION,(8)0.3*
ACT2,40,,,4/NOACTION,,0.7*
ACT,3,4,,,5/WRITEUP*
ACT,4,5,,,6/T-SHOOT,2,0.74*
ACT,4,6,EX,2,7/CND,2,0.26*
PAR,2,4.858,1.0,30.0*
ACT,6,40,(8)16*
ACT,5,7,,,8,,0.17*
```

```
ACT,5,10,,,9,,0.83*
ACT,7,8,EX,3,10/REM LRU*
PAR,3,4.504,0.5,25.0*
ACT,8,9,CO,2,11/AIS TRANS*
ACT,10,11,,,12/R&R*
ACT,12,13,EX,4,13*
PAR,4,5.115,1.0,28.0*
ACT,13,14,CO,2,14/AIS TRANS*
ACT,13,40,,,15*
ACT,15,16(6)17/AIS,2*
ACT,16,17,EX,5,18/BCNRP,,0.42*
PAR,5,7.212,1.0,61.0*
ACT,16,18,EX,6,18/BCRP,,0.51*
PAR,6,12.503,0.4,101.4*
ACT,16,19,EX,7,18/NRTS,,0.07*
PAR,7,5.243,0.5,25.7*
ACT,17,20,,,21*
ACT,18,20,,,22*
ACT,19,20,,,23*
ACT,19,24,CO,48,26/D-NRTS*
ACT,20,21,CO,0.1,24,,,A2.EQ.3*
ACT,20,22,CO,0.1,25,,,A2.EQ.2*
ACT,22,23,EX,8,27/INST*
PAR,8,4.45,1.0,20.0*
ACT,24,21,LO,9,29/INSUP,3*
PAR,9,14.0,0.0,,11.9*
ACT,21,25,CO,0.1,30*
ACT,23,40,,,28*
FIN*
```

APPENDIX E

Q-GERT TRACE AND TRANSACTION PASSAGES

Appendix E is divided into two parts. Appendix E1 is a Q-GERT trace, which gives a sample of the Q-GERT output to enable the user to trace individual transactions through the Q-GERT network. Appendix E2, Q-GERT Transaction Passages, gives the number of actions experienced at each node of the model. Branching coefficients can be confirmed for nodes affected in the model. Column one shows the node number. Column two shows the number of transaction passages through that node. Column three shows the Q-GERT generated branching coefficients for that node. Column four shows the branching coefficient originally modeled.

APPENDIX E1

Q-GERT TRACE

Start Node	End Node	Start Time	End Time	Activity #	Trans Number
1	2	.22	.22	2	2
***	2	-	.22	2	2
2	40	.22	.22	4	2
***	40	-	.22	4	2
1	2	6.55	6.55	2	3
***	2	-	6.55	2	3
2	3	6.55	6.55	3	3
***	3	-	6.55	3	3
3	4	6.55	6.55	5	3
***	4	-	6.55	5	3
4	5	6.55	6.55	6	3
***	5	-	6.55	6	3
5	7	6.55	6.55	8	3
***	7	-	6.55	8	3
7	8	6.55	16.83	10	3
***	8	-	16.83	10	3
8	9	16.83	18.83	11	3
***	9	-	18.83	11	3
15	16	18.83	18.83	17	3
***	16	-	18.83	17	3
16	17	18.99	23.68	18	3
***	17	-	23.68	18	3
17	20	23.68	23.68	21	3
***	20	-	23.68	21	3
20	22	23.68	23.78	25	3
***	22	-	23.78	25	3
22	23	23.78	32.07	27	3
***	23	-	32.07	27	3
23	40	32.07	32.07	28	3
***	40	-	32.07	28	3

APPENDIX E2

Q-GERT TRANSACTION PASSAGES

Node	Transaction Passages	Q-GERT Branch Coeff.	Model Branch Coeff.
1	2000		
2	2000		
3	585	.293	.300
4	585		
5	423	.723	.740
6	162	.277	.260
7	66	.156	.170
8	66		
9	66		
10	357	.844	.830
11	357		
12	357		
13	357		
14	357		
15	423		
16	423		
17	179	.423	.420
18	216	.511	.510
19	28	.066	.070
20	423		
21	357		
22	66		
23	66		
24	28		
25	357		
40	2000		

APPENDIX F

Q-GERT MODEL VERIFICATION CONDESCRIPTIVE STATISTICS, HISTOGRAMS, AND GOODNESS-OF-FIT TESTS

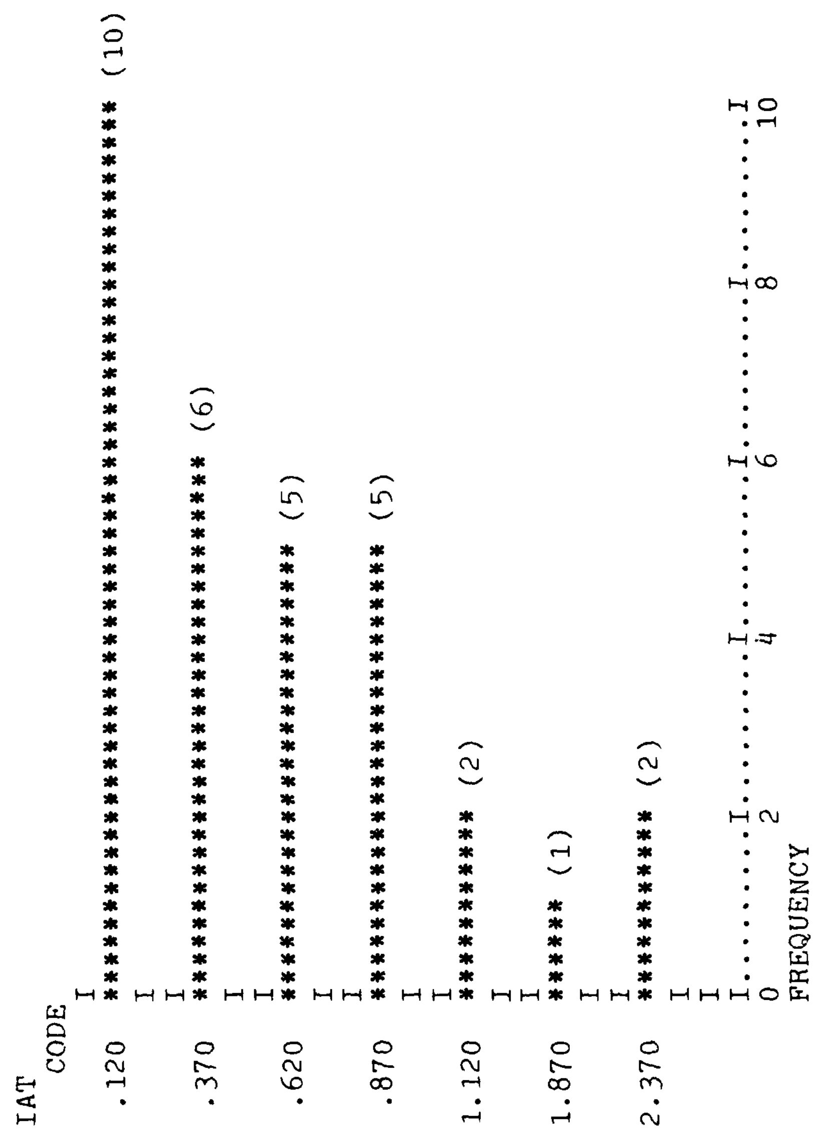
APPENDIX F1

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND
GOODNESS-OF-FIT TEST ON Q-GERT
ON Q-GERT INTERARRIVAL TIMES

VARIABLE IAT

MEAN	.645	STD ERR	.116	STD DEV	.645
VARIANCE	.416	SKEWNESS	1.737	KURTOSIS	2.917
MINIMUM	.100	MAXIMUM	2.500	SUM	20.000

VALID OBSERVATIONS - 31



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
31	2.593	.459

H_o: Q-GERT generated interarrival times of aircraft are exponentially distributed.

H_a: Q-GERT generated interarrival times of aircraft are not exponentially distributed.

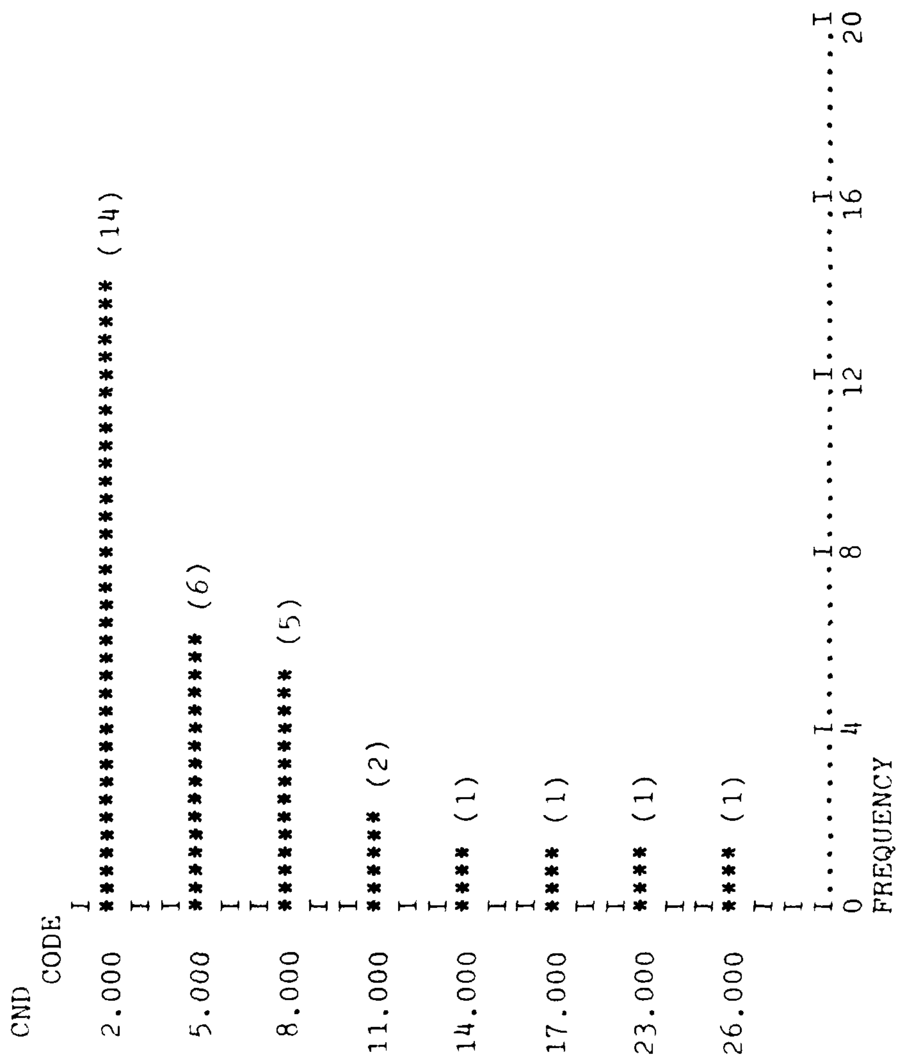
Since .459 (significance) > .01 alpha value, the null hypothesis that the Q-GERT generated interarrival times of aircraft are exponentially distributed cannot be rejected.

APPENDIX F2

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TESTS FOR THE Q-GERT GENERATED TIME-TO-CND RANDOM VARIABLE

VARIABLE	CND				
MEAN	6.387	STD ERR	1.124	STD DEV	6.259
VARIANCE	39.178	SKEWNESS	1.708	KURTOSIS	2.923
MINIMUM	1.000	MAXIMUM	25.000	SUM	198.000

VALID OBSERVATIONS - 31



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
31	1.931	.587

H_o: Q-GERT generated times-to-CND are exponentially distributed

H_a: Q-GERT generated times-to-CND are not exponentially distributed.

Since .587 (significance) > .01 alpha value, the null hypothesis that the Q-GERT generated times-to-CND are exponentially distributed cannot be rejected.

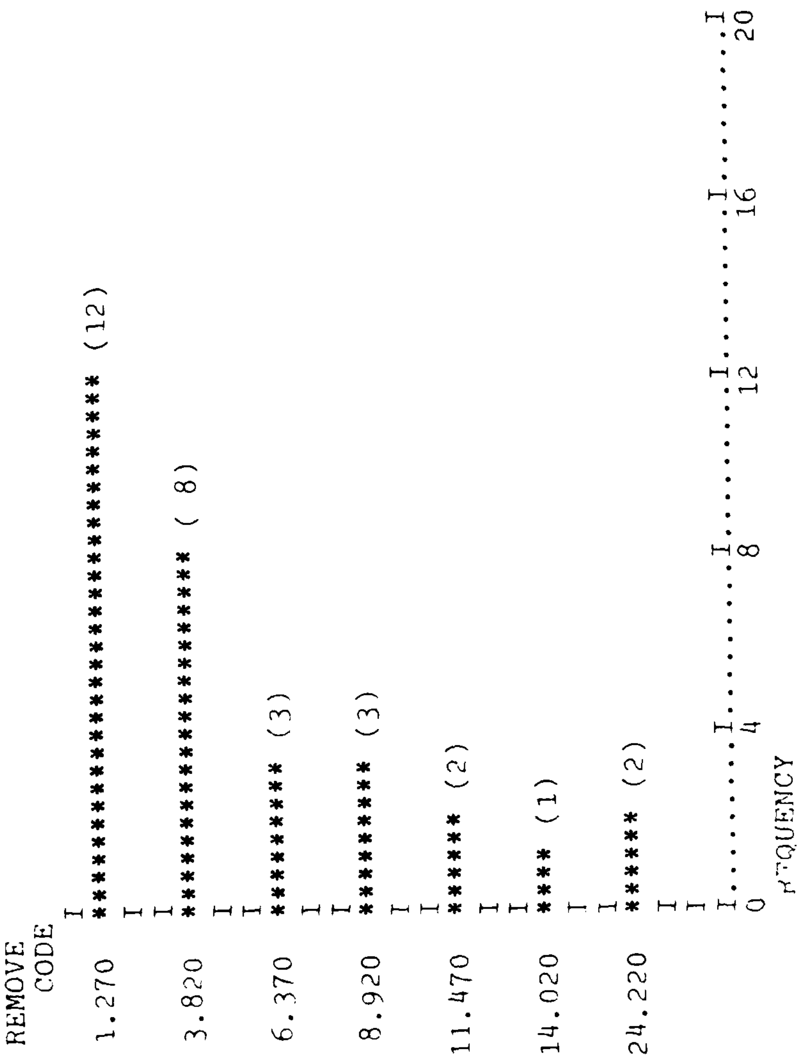
APPENDIX F3

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TEST ON Q-GERT GENERATED TIME-TO-REMOVE RANDOM VARIABLE

VARIABLE REMOVE

MEAN	5.855	STD ERR	1.060	STD DEV	5.899
VARIANCE	34.803	SKEWNESS	1.744	KURTOSIS	3.003
MINIMUM	.500	MAXIMUM	23.000	SUM	181.500

VALID OBSERVATIONS - 31



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
31	3.109	.540

H_o: Q-GERT generated times-to-remove are exponentially distributed.

H_a: Q-GERT generated times-to-remove are not exponentially distributed.

Since .540 (signficance) > .01 alpha value, the null hypothesis that the Q-GERT generated times-to-remove are exponentially distributed cannot be rejected.

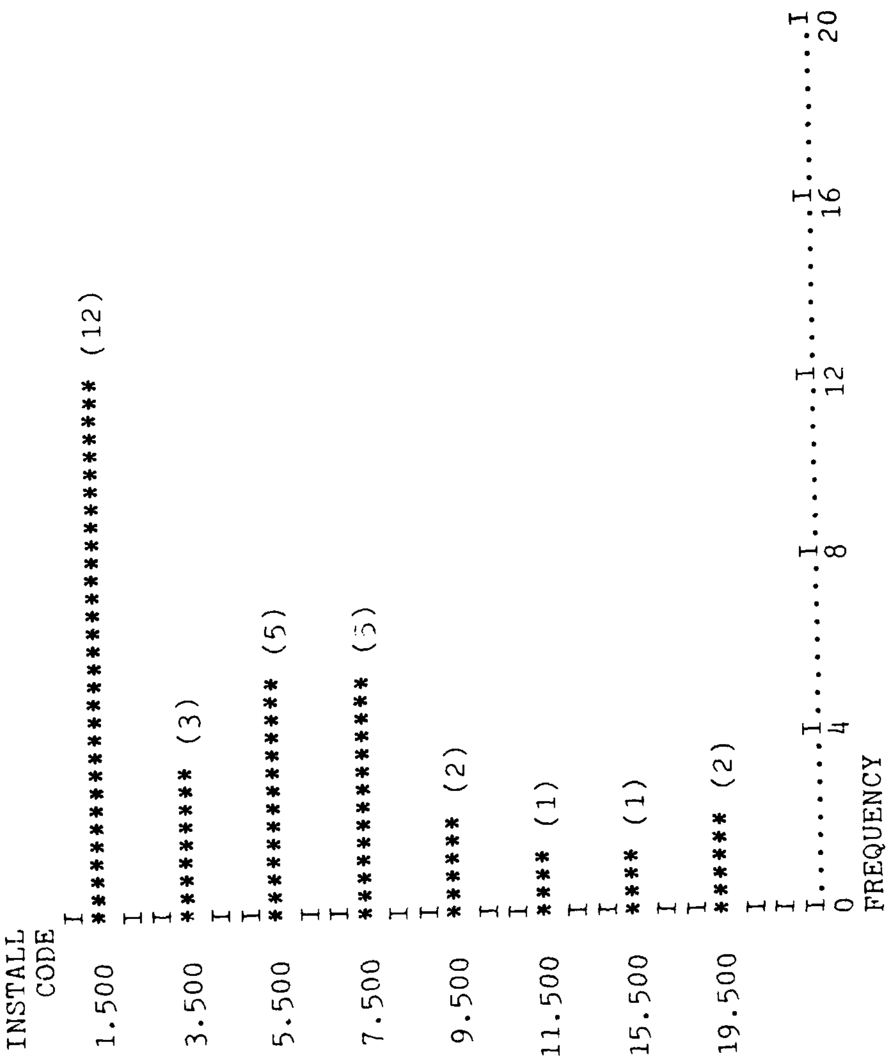
APPENDIX F4

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TEST ON Q-GERT GENERATED TIME-TO-INSTALL RANDOM VARIABLE

```
VARIABLE        INSTALL

MEAN          5.645    STD ERR        .938    STD DEV       5.225
VARIANCE     27.303    SKEWNESS      1.524    KURTOSIS      2.052
MINIMUM       1.000    MAXIMUM      20.000    SUM         175.000

VALID OBSERVATIONS - 31
```



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
31	1.183	.757

H_o: Q-GERT generated times-to-install are exponentially distributed.

H_a: Q-GERT generated times-to-install are not exponentially distributed.

Since .757 (signficance) > .01 alpha value, the null hypothesis that the Q-GERT generated times-to-install are exponentially distributed cannot be rejected.

APPENDIX F5

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TEST ON Q-GERT GENERATED TIME-TO-REMOVE AND REPLACE RANDOM VARIABLE

```
VARIABLE       R&R

MEAN          6.742     STD ERR        1.182     STD DEV         6.583
VARIANCE     43.331     SKEWNESS       1.774     KURTOSIS        3.145
MINIMUM       1.000     MAXIMUM       26.000     SUM           209.000

VALID OBSERVATIONS -  31
```

```
R&R
CODE
        I
  1.900 **************************** (14)
        I
        I
  4.700 ************ (6)
        I
        I
  7.500 ****** (3)
        I
        I
 10.300 **** (2)
        I
        I
 13.100 ****** (3)
        I
        I
 15.900 ** (1)
        I
        I
 27.100 **** (2)
        I
        I
        I.........I.........I.........I.........I.........I
        0         4         8        12        16        20
                          FREQUENCY
```

CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
31	.809	.847

H_o: Q-GERT generated times-to-remove and replace are exponentially distributed.

H_a: Q-GERT generated times-to-remove and replace are not exponentially distributed.

Since .847 (significance) > .01 alpha value, the null hypothesis that the Q-GERT generated times-to-remove and replace are exponentially distributed cannot be rejected.

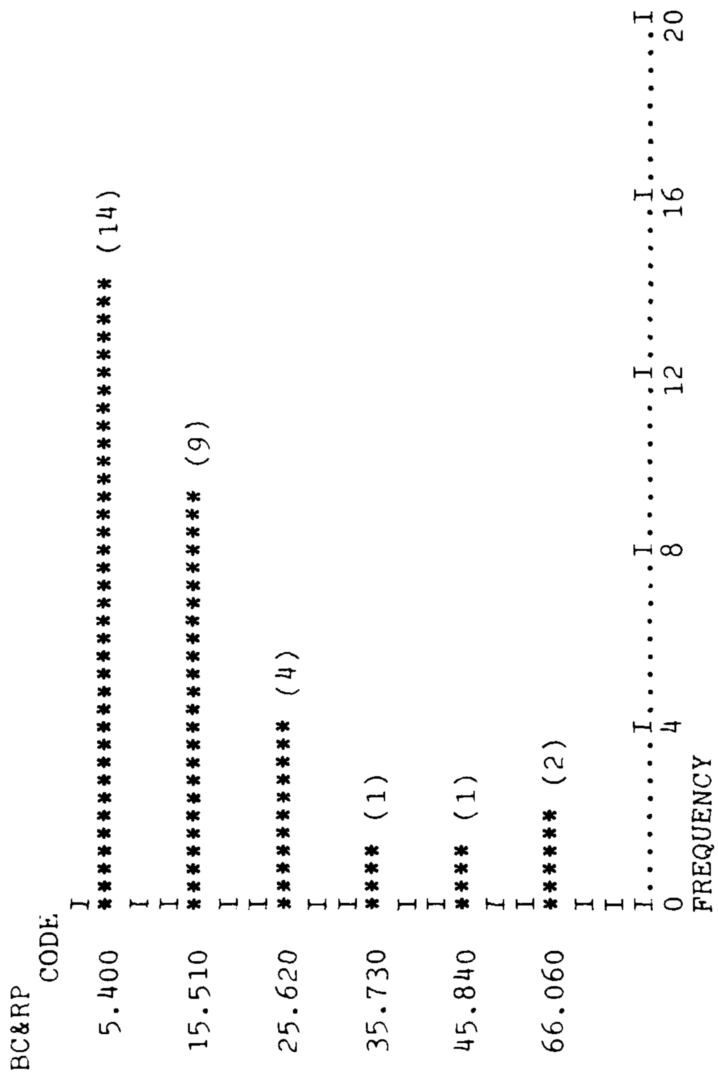
APPENDIX F6

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TEST ON Q-GERT GENERATED TIME-TO-BENCH CHECK AND REPAIR RANDOM VARIABLE

VARIABLE BC&RP

MEAN	16.006	STD ERR	2.923	STD DEV	16.274
VARIANCE	264.836	SKEWNESS	1.679	KURTOSIS	2.860
MINIMUM	.400	MAXIMUM	63.000	SUM	496.200

VALID OBSERVATIONS - 31



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
31	1.574	.813

H_o: Q-GERT generated times-to-bench check and repair are exponentially distributed.

H_a: Q-GERT generated times-to-bench check and repair are not exponentially distributed.

Since .813 (significance) > .01 alpha value, the null hypothesis that the Q-GERT generated times-to-bench check and repair are exponentially distributed cannot be rejected.

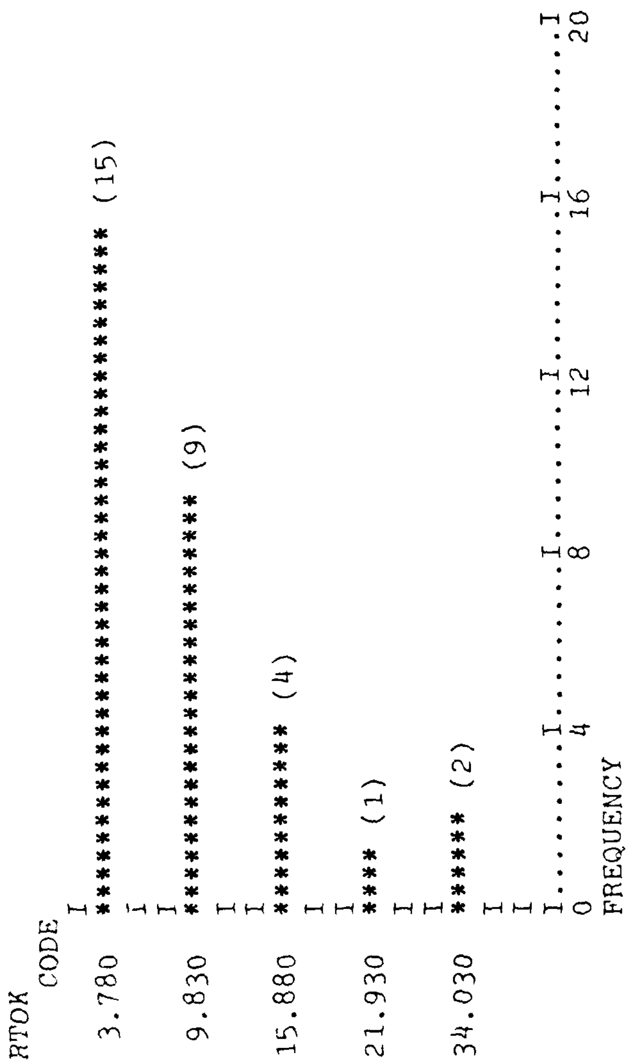
APPENDIX F7

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TEST ON Q-GERT GENERATED TIME-TO-BENCH CHECK WITH NO REPAIR (RTOK) RANDOM VARIABLE

VARIABLE RTOK

MEAN	9.323	STD ERR	1.672	STD DEV	9.307
VARIANCE	86.626	SKEWNESS	1.764	KURTOSIS	3.120
MINIMUM	1.000	MAXIMUM	37.000	SUM	289.000

VALID OBSERVATIONS - 31



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SQUARE	SIGNIFICANCE
31	1.705	.636

H_o: Q-GERT generated times-to-bench check with no repair (RTOK) are exponentially distributed.

H_a: Q-GERT generated times-to-bench check with no repair (RTOK) are not exponentially distributed.

Since .636 (significance) > .01 alpha value, the null hypothesis that the Q-GERT generated times-to-bench check with no repair (RTOK) are exponentially distributed cannot be rejected.

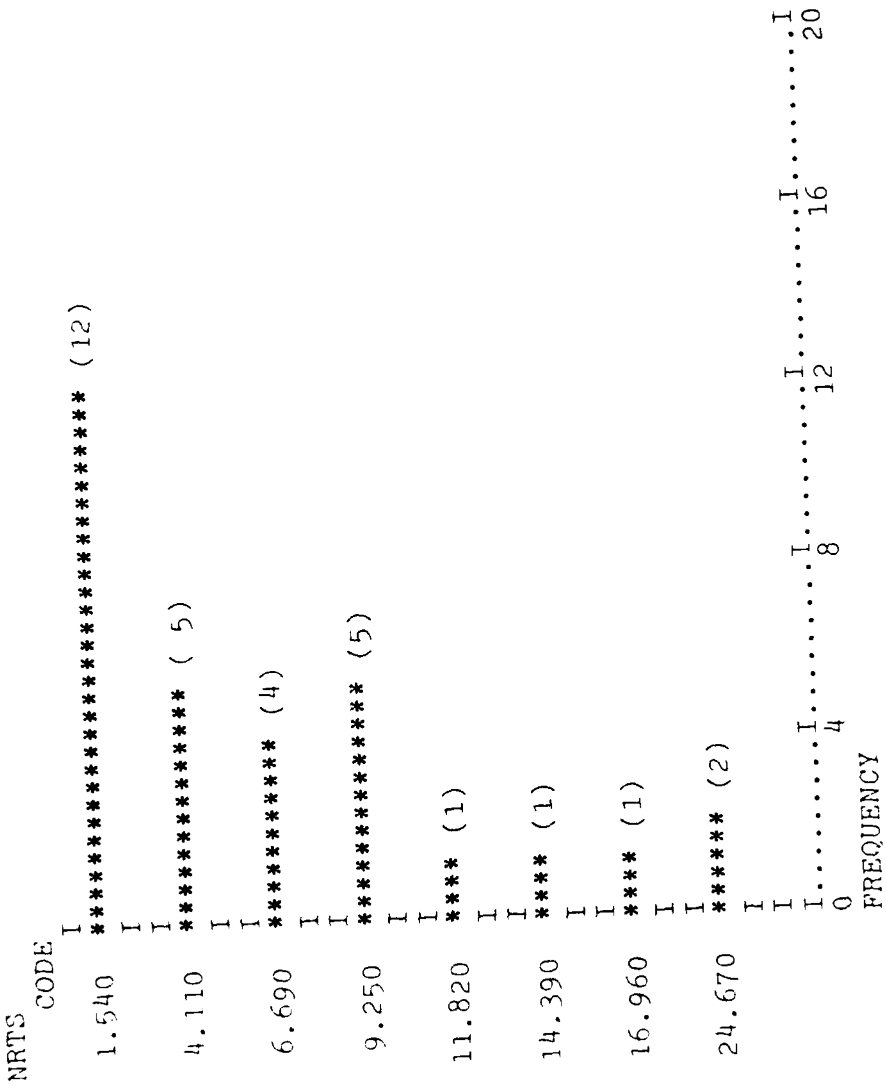
APPENDIX F8

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TEST ON Q-GERT GENERATED TIME-TO-NRTS RANDOM VARIABLE

VARIABLE NRTS

MEAN	6.242	STD ERR	1.174	STD DEV	6.534
VARIANCE	42.698	SKEWNESS	1.731	KURTOSIS	2.801
MINIMUM	.500	MAXIMUM	25.000	SUM	193.500

VALID OBSERVATIONS - 31



CHI-SQUARE GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - EXPONENTIAL

CASES	CHI-SUARE	SIGNIFICANCE
31	.546	.909

H_o: Q-GERT generated times-to-NRTS are exponentially distributed.

H_a: Q-GERT generated times-to-NRTS are not exponentially distributed.

Since .909 (significance) > .01 alpha value, the null hypothesis that the Q-GERT generated times-to-NRTS are exponentially distributed cannot be rejected.

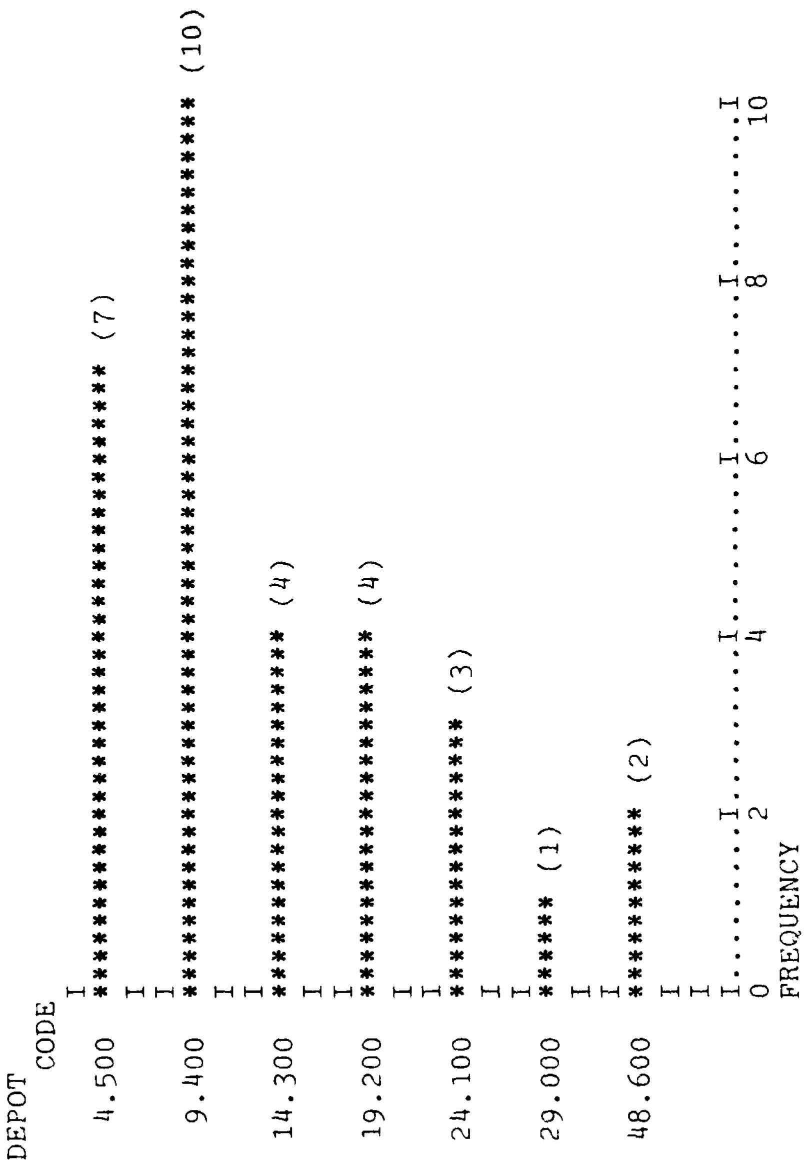
APPENDIX F9

CONDESCRIPTIVE STATISTICS, HISTOGRAM, AND GOODNESS-OF-FIT TEST ON Q-GERT GENERATED DEPOT REPAIR TIME RANDOM VARIABLE

VARIABLE DEPOT

MEAN	14.613	STD ERR	2.119	STD DEV	11.797
VARIANCE	139.178	SKEWNESS	1.870	KURTOSIS	3.706
MINIMUM	2.000	MAXIMUM	51.000	SUM	453.000

VALID OBSERVATIONS - 31



KOLMOGOROV-SMIRNOV GOODNESS-OF-FIT TEST

TEST DISTRIBUTION - NORMAL (MEAN = 2.413, STD DEV = .738)

CASES = 31	MAX (ABS DIFF) = .1013
K-S Z = 2.427	2-TAILED P = .000

$n = 31$; $\alpha = .01$ Lilliefors Table Value = .185

H_o: Distribution of depot maintenance times are log-normal; logarithms of depot maintenance times are normally distributed.

H_a: Distribution of depot maintenance times are not lognormal; logarithms of depot maintenance times are not normally distributed.

Since .1013 < .185, cannot reject the null hypothesis that depot maintenance times are lognormally distributed.

APPENDIX G

Q-GERT GENERATED RESPONSE SURFACES

Appendix G is the Q-GERT generated output of the simulation model. Part I shows the results for the reduction in CND actions by one-third and then two-thirds. Part II shows the results for the reduction in RTOK actions by one-third and then two-thirds. Part III shows the results for the combined reduction in CND/RTOK actions by one-third and then two-thirds. Column one shows the run number, each consisting of 2000 aircraft generated to OR status. Column two shows the reduction: baseline; actions reduced by one-third; and actions reduced by two-thirds. Column three shows the time required to generate the 2000 OR aircraft.

CND ACTIONS

Run #	Reduction	Time to Generate OR Aircraft
1	Baseline	4113.18
	1/3	4502.30
	2/3	4423.43
2	Baseline	3871.84
	1/3	4135.66
	2/3	3999.63
3	Baseline	4499.28
	1/3	4283.99
	2/3	4570.46
4	Baseline	4546.18
	1/3	4357.37
	2/3	4162.61
5	Baseline	4354.65
	1/3	3796.08
	2/3	4054.12
6	Baseline	4298.91
	1/3	4170.20
	2/3	4062.36
7	Baseline	4002.81
	1/3	3963.80
	2/3	3896.07
8	Baseline	4595.18
	1/3	4172.00
	2/3	4116.72
9	Baseline	4756.06
	1/3	4234.09
	2/3	4306.90
10	Baseline	4774.64
	1/3	4885.22
	2/3	4521.49
11	Baseline	3800.83
	1/3	4237.45
	2/3	3898.34

Run #	Reduction	Time to Generate OR Aircraft
12	Baseline	4257.87
	1/3	4480.81
	2/3	4450.81
13	Baseline	4399.31
	1/3	3722.07
	2/3	4351.83
14	Baseline	4020.53
	1/3	4479.39
	2/3	4209.53
15	Baseline	4697.73
	1/3	3830.01
	2/3	4216.32
16	Baseline	4133.57
	1/3	4594.05
	2/3	4474.28
17	Baseline	4592.14
	1/3	4221.57
	2/3	3868.25
18	Baseline	4000.42
	1/3	4241.55
	2/3	3872.65
19	Baseline	4482.20
	1/3	4259.93
	2/3	4576.96
20	Baseline	4081.48
	1/3	4342.85
	2/3	4397.11
21	Baseline	4628.55
	1/3	4208.20
	2/3	4464.18
22	Baseline	4184.24
	1/3	4681.33
	2/3	4515.71
23	Baseline	4151.50
	1/3	4297.67
	2/3	4175.94

Run #	Reduction	Time to Generate OR Aircraft
24	Baseline	4101.66
	1/3	4210.61
	2/3	4631.96
25	Baseline	4357.79
	1/3	3918.42
	2/3	4408.26
26	Baseline	4206.73
	1/3	4082.15
	2/3	3806.68
27	Baseline	4662.79
	1/3	4634.48
	2/3	4038.55

RTOK ACTIONS

Run #	Reduction	Time to Generate OR Aircraft
1	Baseline	4113.18
	1/3	3757.19
	2/3	3940.45
2	Baseline	3871.84
	1/3	3799.76
	2/3	3603.03
3	Baseline	4499.28
	1/3	4474.78
	2/3	3307.95
4	Baseline	4546.18
	1/3	3799.77
	2/3	3381.22
5	Baseline	4354.65
	1/3	4229.76
	2/3	3511.08
6	Baseline	4298.91
	1/3	3963.86
	2/3	4219.40
7	Baseline	4002.81
	1/3	4003.61
	2/3	3436.70
8	Baseline	4595.18
	1/3	3644.42
	2/3	3133.20
9	Baseline	4756.06
	1/3	4126.29
	2/3	3192.82
10	Baseline	4774.64
	1/3	4362.12
	2/3	3448.75
11	Baseline	3800.83
	1/3	3871.99
	2/3	3830.09

Run #	Reduction	Time to Generate OR Aircraft
12	Baseline	4257.87
	1/3	4309.59
	2/3	3429.82
13	Baseline	4399.31
	1/3	3651.45
	2/3	3445.63
14	Baseline	4020.53
	1/3	3527.64
	2/3	4067.34
15	Baseline	4697.73
	1/3	3545.36
	2/3	3701.06
16	Baseline	4133.57
	1/3	3906.25
	2/3	3162.22
17	Baseline	4592.14
	1/3	4025.86
	2/3	3639.44
18	Baseline	4000.42
	1/3	4268.04
	2/3	3570.64
19	Baseline	4482.20
	1/3	3826.95
	2/3	3676.42
20	Baseline	4081.48
	1/3	3785.12
	2/3	3657.87
21	Baseline	4628.55
	1/3	3791.80
	2/3	4087.97
22	Baseline	4184.24
	1/3	4167.24
	2/3	3835.77
23	Baseline	4151.50
	1/3	4508.28
	2/3	3779.45

Run #	Reduction	Time to Generate OR Aircraft
24	Baseline	4101.66
	1/3	3862.34
	2/3	3519.28
25	Baseline	4357.79
	1/3	3630.27
	2/3	3208.87
26	Baseline	4206.73
	1/3	4342.88
	2/3	3897.56
27	Baseline	4662.79
	1/3	4047.91
	2/3	3826.16

CND/RTOK ACTIONS

Run #	Reduction	Time to Generate OR Aircraft
1	Baseline	4113.18
	1/3	3963.25
	2/3	3527.84
2	Baseline	3871.84
	1/3	3624.58
	2/3	3384.96
3	Baseline	4499.28
	1/3	3981.71
	2/3	3337.28
4	Baseline	4546.18
	1/3	4139.16
	2/3	3567.55
5	Baseline	4354.65
	1/3	3571.68
	2/3	3234.54
6	Baseline	4298.91
	1/3	3985.06
	2/3	3324.72
7	Baseline	4002.81
	1/3	3539.96
	2/3	3136.87
8	Baseline	4595.18
	1/3	3938.77
	2/3	2714.62
9	Baseline	4756.06
	1/3	4227.86
	2/3	2926.21
10	Baseline	4774.64
	1/3	3993.40
	2/3	3571.81
11	Baseline	3800.83
	1/3	3748.41
	2/3	3092.34

Run #	Reduction	Time to Generate OR Aircraft
12	Baseline	4257.87
	1/3	3915.31
	2/3	3361.22
13	Baseline	4399.31
	1/3	3613.72
	2/3	3030.78
14	Baseline	4020.53
	1/3	3691.70
	2/3	3496.07
15	Baseline	4697.73
	1/3	3818.68
	2/3	3332.63
16	Baseline	4133.57
	1/3	3508.67
	2/3	2617.80
17	Baseline	4592.14
	1/3	3849.06
	2/3	2791.11
18	Baseline	4000.42
	1/3	4106.19
	2/3	3162.24
19	Baseline	4482.20
	1/3	3477.97
	2/3	3183.38
20	Baseline	4081.48
	1/3	3569.23
	2/3	3502.08
21	Baseline	4628.55
	1/3	3658.68
	2/3	3358.30
22	Baseline	4184.24
	1/3	3858.90
	2/3	3315.09
23	Baseline	4151.50
	1/3	3743.99
	2/3	3373.56

Run #	Reduction	Time to Generate OR Aircraft
24	Baseline	4101.66
	1/3	3600.25
	2/3	2963.21
25	Baseline	4357.79
	1/3	3746.76
	2/3	3038.69
26	Baseline	4206.73
	1/3	3485.84
	2/3	3158.91
27	Baseline	4662.79
	1/3	4059.65
	2/3	3299.87

APPENDIX H

ANALYSIS OF VARIANCE OF RESPONSE SURFACE

Appendix H is divided into six parts. Appendix H1 through H3 are parametric analyses of the response surface shown in Appendix G and was used to determine if parametric statistics could be used to analyze the results. Appendix H4 through H6 are the Duncan's Multiple Range and Variance tests used to determine if the average time to generate operationally ready aircraft are statistically different.

APPENDIX H1

HOMOGENEITY OF VARIANCE TEST OF CND ACTIONS

TESTS FOR HOMOGENEITY OF VARIANCES

COCHRANS C = MAX VARIANCE/SUM (VARIANCES)

= .3585, P = 1.000 (approx.)

BARTLETT-BOX F = .133, P = .875

MAXIMUM VARIANCE/MINIMUM VARIANCE = 1.214

H_o: Variances of average time to generate OR aircraft are equal for Baseline, CND's reduced by 1/3, and CND's reduced by 2/3.

H_a: Variances of average time to generate OR aircraft are not equal for Baseline CND's reduced by 1/3, and CND's reduced by 2/3.

Since the P values for Cochran's C and Bartlett-Box tests are greater than 0.000, cannot reject the null hypothesis that the variances are equal. Therefore, ANOVA can be used to test the differences of means.

APPENDIX H2

HOMOGENEITY OF VARIANCE TEST OF RTOK ACTIONS

TESTS FOR HOMOGENEITY OF VARIANCES

COCHRANS C = MAX VARIANCE/SUM (VARIANCES)

= .3512, P = 1.000 (approx.)

BARTLETT-BOX F = .030, P = .970

MAXIMUM VARIANCE/MINIMUM VARIANCE = 1.100

H_o: Variances of average time to generate OR aircraft are equal for Baseline, RTOK's reduced by 1/3, and RTOK's reduced by 2/3.

H_a: Variances of average time to generate OR aircraft are not equal for Baseline, RTOK's reduced by 1/3, and RTOK's reduced by 2/3.

Since the P values for Cochran's C and Bartlett-Box tests are greater than 0.000, cannot reject the null hypothesis that the variances are equal. Therefore, ANOVA can be used to test the difference of means.

APPENDIX H3

HOMOGENEITY OF VARIANCE TEST OF CND/RTOK ACTIONS

TESTS FOR HOMOGENEITY OF VARIANCES

COCHRANS C = MAX VARIANCE/SUM (VARIANCES)

= .4095, P = .469 (approx.)

BARTLETT-BOX F = .788, P = .455

MAXIMUM VARIANCE/MINIMUM VARIANCE = 1.644

> H_o: Variances of average time to generate OR aircraft are equal for Baseline, CND/RTOK's reduced by 1/3, and CND/RTOK's reduced by 2/3.

> H_a: Variances of average time to generate OR aircraft are not equal for Baseline, CND/RTOK's reduced by 1/3, and CND/RTOK's reduced by 2/3.

Since the P values for Cochran's C and Bartlett-Box tests are greater than 0.000, cannot reject the null hypothesis that the variances are equal. Therefore, ANOVA can be used to test the difference of means.

APPENDIX H4

DUNCAN'S MULTIPLE RANGE TEST AND ONE-WAY ANALYSIS OF VARIANCE OF CND ACTIONS

MULTIPLE RANGE TEST

DUNCAN PROCEDURE

RANGES FOR THE .050 LEVEL -

2.82 2.96

SUBSET 1

GROUP	CND 2/3	CND 1/3	BASELINE
MEAN	4239.67	4257.16	4317.48

H_o: The means of Baseline, CND's reduced by 1/3, and CND's reduced by 2/3 are equal.

H_a: The means of Baseline, CND's reduced by 1/3, and CND's reduced by 2/3 are not equal.

Since Subset 1 contains all three mean values, cannot reject the null hypothesis that the means of Baseline, CND's reduced by 1/3, and CND's reduced by 2/3 are equal.

ONE-WAY ANALYSIS OF VARIANCE

GROUP	COUNT	MEAN	STD DEV	95 PCT CONF INT FOR MEAN
Baseline	27	4317.48	279.37	4206.97 to 4427.99
CND 1/3	27	4257.16	274.48	4148.58 to 4365.74
CND 2/3	27	4239.67	253.59	4139.36 to 4339.99
TOTAL	81	4271.44		

H_o: The difference in means of Baseline, CND's reduced by 1/3, and CND's reduced by 2/3 are not statistically significant.

H_a: The difference in means of Baseline, CND's reduced by 1/3, and CND's reduced by 2/3 are statistically significant.

Since the 95% Confidence Interval for all three actions hook each other, we cannot reject the null hypothesis that the means of Baseline, CND's reduced by 1/3, and CND's reduced by 2/3 are not statistically significant.

APPENDIX H5

DUNCAN'S MULTIPLE RANGE TEST AND ONE-WAY ANALYSIS OF VARIANCE OF RTOK ACTIONS

MULTIPLE RANGE TEST

DUNCAN PROCEDURE

RANGES FOR THE .050 LEVEL -

2.82 2.96

SUBSET 1

GROUP	RTOK 2/3
MEAN	3611.45

SUBSET 2

GROUP	RTOK 1/3
MEAN	3971.50

SUBSET 3

GROUP	BASELINE
MEAN	4317.48

H_o: The means of Baseline, RTOK's reduced by 1/3, and RTOK's reduced by 2/3 are equal.

H_a: The means of Baseline, RTOK's reduced by 1/3, and RTOK's reduced by 2/3 are not equal.

Since the means of all three actions are in different subsets, reject the null hypothesis. We can accept the alternative hypothesis that the means of Baseline, RTOK's reduced by 1/3, and RTOK's reduced by 2/3 are not equal.

ONE-WAY ANALYSIS OF VARIANCE

GROUP	COUNT	MEAN	STD DEV	95 PCT CONF INT FOR MEAN
Baseline	27	4317.48	279.37	4206.97 to 4427.99
RTOK 1/3	27	3971.50	283.96	3859.17 to 4083.83
RTOK 2/3	27	3611.45	293.06	3495.52 to 3727.38
TOTAL	81	3966.81		

H_o: The difference in means of Baseline, RTOK's reduced by 1/3, and RTOK's reduced by 2/3 are not statistically significant.

H_a: The difference in means of Baseline, RTOK's reduced by 1/3, and RTOK's reduced by 2/3 are statistically significant.

Since the 95% Confidence Interval for all three actions do not hook each other, we reject the null hypothesis and accept the alternative that the difference in means of Baseline, RTOK's reduced by 1/3, and RTOK's reduced by 2/3 are statistically significant.

APPENDIX H6

DUNCAN'S MULTIPLE RANGE TEST AND ONE-WAY ANALYSIS OF VARIANCE OF CND/RTOK ACTIONS

MULTIPLE RANGE TEST

DUNCAN PROCEDURE

RANGES FOR THE .050 LEVEL -

2.82 2.96

SUBSET 1

GROUP	CND/RTOK 2/3
MEAN	3214.95

SUBSET 2

GROUP	CND/RTOK 1/3
MEAN	3793.28

SUBSET 3

GROUP	BASELINE
MEAN	4317.48

H_o: The means of Baseline, CND/RTOK's reduced by 1/3, and CND/RTOK's reduced by 2/3 are equal.

H_a: The means of Baseline, CND/RTOK's reduced by 1/3, and CND/RTOK's reduced by 2/3 are not equal.

Since the means of all three actions are in different subsets, reject the null hypothesis. We can accept the alternative hypothesis that the means of Baseline, CND/RTOK's reduced by 1/3, and CND/RTOK's reduced by 2/3 are not equal.

ONE-WAY ANALYSIS OF VARIANCE

GROUP	COUNT	MEAN	STD DEV	95 PCT CONF INT FOR MEAN
Baseline	27	4317.48	279.37	4206.97 to 4427.99
CND/RTOK 1/3	27	3793.28	217.87	3707.09 to 3879.46
CND/RTOK 2/3	27	3214.95	255.09	3114.04 to 3315.86
TOTAL	81	3775.24		

H_o: The difference in means of Baseline, CND/RTOK's reduced by 1/3, and CND/RTOK's reduced by 2/3 are not statistically significant.

H_a: The difference in means of Baseline, CND/RTOK's reduced by 1/3, and CND/RTOK's reduced by 2/3 are statistically significant.

Since the 95% Confidence Interval for all three actions do not hook each other, we reject the null hypothesis and accept the alternative that the difference in means of Baseline, CND/RTOK's reduced by 1/3, and CND/RTOK's reduced by 2/3 are statistically significant.

SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

Anderson, David R., Sweeney, Dennis J., & Williams, Thomas A. An introduction to management science quantitative approaches to decision making (3rd ed.). St. Paul MN: West Publishing Company, 1982.

Arnett, J. M. Toward validation of computer simulation models in operational test and evaluation. Unpublished master's thesis, School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB OH, 1979.

Baran, Harry A. Effect of test result uncertainty on the performance of a context-free troubleshooting task. Unpublished master's thesis, LSSR 86-82, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH, January 1983. ADA 128584

Bartee, Edwin M. Engineering experimental design fundamentals. Englewood Cliffs NJ: Prentice-Hall, Inc., 1968.

Bobko, Lieutenant Colonel Peter J., USAF. Department of Operational Sciences, AFIT/EN, Wright-Patterson AFB OH. Course SM 6.25, "Logistics Systems Analysis and Design," Class 1983S. Lectures. 3 January 1983 through 9 March 1983.

Bryson, Gary C., Husby, David J., & Webb, Michael E. A decision support system for acquisition of F-16 avionics intermediate shop test sets using the systems science paradigm and Q-GERT. Unpublished master's thesis, LSSR 11-82, School of Systems and Logistics, Wright-Patterson AFB OH, September 1982. ADA 123051

Caracillo, Michael. Branch Chief, Data Analysis Branch, F-16 Data Analysis Division, Wright-Patterson AFB OH. Personal interview. 25 February 1983 through 11 March 1983.

Dynamics Research Corporation. Automatic test equipment (ATE)-centralized data system (CDS) user's manual organization and intermediate levels. DRC Document E606IU, Wilmington MA, 16 February 1982.

General Dynamics. F-16 avionics intermediate shop, technical volume 2, RF test station. Ft. Worth TX, 17 October 1975.

Gutmann, R. W. U. S. Government Accounting Office (GAO) Logistics Communication Division. Letter, Subject: Survey of DOD's management of automatic and general purpose electronic test equipment, to Harold Brown, U. S. Secretary of Defense, 4 September 1980. LD 48229A

Herner, Alan E., Miller, T. M., & Genet, Russel M. Diagnostic errors and human factors in built-in-test (BIT). Unpublished technical report (unnumbered), AFHRL/LRLA, Wright-Patterson AFB OH, April 1981.

Institute of Defense Analyses, Program Analysis Division. Built-in-test equipment requirements workshop: Workshop presentation. IDA Paper P-1600, Arlington VA, August 1981.

King, Michel A. Operations Research Analyst, Logistics and Technical Training Division, Air Force Human Resources Laboratory, Wright-Patterson AFB OH. Personal interview. 11 February 1983.

King, Michel A., and others. A model of the diagnostic process for maintenance of avionics. Unpublished research report, Air Force Human Resources Laboratory, AFHRL/LRLA, Wright-Patterson AFB OH, 1982.

Morehead, R. C., Brinkman, A. T., & Chambers, A. W. Integrated factory test planning for the F-16 radar. Logistics Direction, January 1979, 30-36.

Newman, Robert T. Maintenance Data Analyst, Maintenance Data Collection System, Directorate of Engineering and Computer Resources, Analysis and Support Division, Wright-Patterson AFB OH. Telephone interview. 31 May 1983.

Norton, Leslie M., and others. International logistics management. In Press, 1983.

Owens, P. R., St. John, M. R., & Lamb, F. D. Avionics maintenance study. Unpublished technical report (AFAL-TR-77-90), Air Force Avionics Laboratory, Wright-Patterson AFB OH, June 1977.

Pritsker, A. Alan B. Modeling and analysis using Q-GERT networks (2nd ed.). New York: John Wiley & Sons, Inc., 1979.

Schoderbek, Charles G., Schoderbek, Peter P., & Kefalas, Asterios G. Management systems conceptual considerations (Rev. ed.). Dallas TX: Business Publications, Inc., 1980.

School of Systems and Logistics, Air Force Institute of Technology (ATC). *Compendium of authenticated systems and logistics terms, definitions and acronyms*. Wright-Patterson AFB OH, 1981.

Shannon, Robert E. *Systems simulation-the art and science*. Englewood Cliffs NJ: Prentice-Hall, Inc., 1975.

Stacey, Captain Ted. F-16 Avionics Officer, Headquarters Tactical Air Command, Directorate of Logistics, Avionics Division, Langley AFB VA. Telephone interview. 18 February 1983.

Westinghouse Electric Corporation. *Avionics diagnostics pilot study*. Task Final Report No. 0016-3, Air Force Human Resources Laboratory, Wright-Patterson AFB OH, January 1983.

Westinghouse Electric Corporation. *Logistics feasibility and team training impact studies interim report*. AFHRL Purchase Request No. FY8993-82-00012, Air Force Human Resources Laboratory, Wright-Patterson AFB OH, December 1981.

B. RELATED SOURCES

Air Force Audit Agency. Baselevel management of bench mock-ups and automatic test equipment. Unpublished technical report No. 95441, U. S. Army Logistics Management Center, Fort Lee VA, September 1979. LD 45009A

Air Force Human Resources Laboratory. Reducing avionics diagnostic errors. AFHRL Contract No. FY8993-82-00012, Wright-Patterson AFB OH, December 1981.

Chesley, Dennis H. Digital test onsite: A growing concern. Spectrum, Winter 1981, 20-24.

Erdman, S., & Shiloh, L. J. ATE directions. Logistics Direction, September 1982, 8-15.

General Dynamics. F-16 avionics system malfunction analysis (organizational level). Unpublished technical report No. 16PR-1C10A, Fort Worth Division, Fort Worth TX, July 1979.

General Dynamics. F-16 organizational level fault isolation technical coordination meeting (user meeting). Unpublished technical report, unnumbered, Fort Worth Division, Fort Worth TX, June 1981.

Gilbert, Norman F., & Tarulli, Michael G. An analysis of the effect of tester replaceable unit spares levels on automatic test station availability. Unpublished master's thesis, LSSR 7-82, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH, September 1982. ADA 123000

Guerra, Joel A., Lesko, Andrew J., & Periera, Jose G. Operating and support cost model for avionics automatic test equipment. Unpublished master's thesis, LSSR 21-79B, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH, September 1979. ADA 075586

House, Cecil H. Automated avionics test station status reporting system. Unpublished technical report No. 780102, Air Force Logistics Management Center, Gunter AFS AL, September 1979.

Hughes Aircraft Company. Analysis of built-in-test (BIT) false alarm conditions. RADS-TR-81, Rome Air Development Center, Griffiss AFB NY, February 1981.

Hull, C. Hadlai, & Nie, Norma H. SPSS new procedures and facilities for releases 7-9. New York: McGraw-Hill Book Company, 1981.

Keller, T. A., & Blair, L. J. MATE-keeping the Air Force in fighting shape. Logistics Direction, January 1981, 2-8.

Kimberlin, William M. C-5 malfunction detection analysis and recording system (MADARS). Unpublished technical report, unnumbered, Military Airlift Command, Pope AFB NC, March 1982. AD B063384

Lilliefors, Hubert W. On the kolmogorov-smirnov test for the exponential distribution with mean unknown. American Statistical Association Journal, March 1969, 387-389.

Lilliefors, Hubert W. On the kolmogorov-smirnov test for normality with mean and variance unknown. American Statistical Association Journal, June 1969, 399-402.

Lowell, Captain James Russell, USAF. An analysis of Air Force avionic test station utilization using Q-GERT modeling and simulation. Unpublished master's thesis. AFIT/CI/79-265T, Arizona State University, December 1979. AD A091478

Lunsford, G. H., and others. F-15 AIS troubleshooting/fault isolation analysis. Unpublished technical report, unnumbered, Air Force Logistics Management Center, Gunter AFS AL, September 1980.

Masters, H. M. Integrated self-instructive test equipment (ISITE) a new concept in automatic test equipment enhancement. Logistics Direction, September 1982, 28-34.

McClave, James T., & Benson, P. George. Statistics for business and economics. San Francisco: Dellen Publishing Company, 1982.

Menking, Major Hugh M. East, Major Jared G., & Peterson, Billie D. Computer controlled automatic test equipment (CATE). Unpublished research report No. FM 182, Modern Army Selected Systems Test, Evaluation, and Reviews (MASSTER), Fort Hood TX, April 1976. AD B010594

Morehead, R. C., & Moon, E. R. The electronics repair center generic/modular automatic test equipment for radar system application. Logistics Direction, September 1982, 17-22.

Neumann, George W. Automatic testing, A tool for improving fleet readiness. Unpublished technical report, unnumbered, Naval Material Command, Washington DC, March 1976. AD A022307

Novak, Frederick V., & Winters, Henry. Automatic test equipment software life cycle cost simulation model validation. Unpublished master's thesis, LSSR 16-78A, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH, June 1978. ADA 059182

Proctor, G. E., & Ramage, W. W. Human aspects of automatic test equipment. Logistics Direction, January 1979, 13-18.

Rand Corporation. A stochastic network approach to test and checkout. Rand Document P-4486, Santa Monica CA, October 1970.

Reusche, Michael A., & Wasem, Vaughn D. Simulation and manpower forecasting models for tactical aerial port operations in a contingency environment. Unpublished master's thesis, LSSR 4-82, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH, September 1982. ADA 122846

Reynolds, Daniel E. Assistant Professor, Department of Mathematics, AFIT/EN, Wright-Patterson AFB OH. Course MA 5.25, "Statistics for Logistics Managers," Class 1983S. Lectures. 12 July 1982 through 17 September 1982.

Riche, Kim A. Analysis of F-16 radar discrepancies. Unpublished master's thesis, AFIT/GE/EE/82D-56, School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB OH, December 1982.

Ringel, Melvin B., Mooney, David H., & Long, William H., III. Detection and false alarm performance of the F-16 airborne pulse doppler radar (AN/APG-66). Unpublished research report No. 81-0203, Westinghouse Electric Corporation, Baltimore MD, June 1981.

Smith, Robert E., & Elm, Robert J. Automated maintenance system test program evaluation report for increments I through V. Unpublished technical report No. 760720-1, Air Force Logistics Management Center, Gunter AFS AL, June 1981.

Sperry Corporation. Automatic test equipment. Final report No. RL-CR-80-3, U. S. Army Missile Command, Redstone Arsenal AL, February 1980.

Westinghouse Corporation. AN/APG-66 a fighter pilot's radar. Westinghouse Defense, Baltimore MD, undated.

Westinghouse Electric Corporation. Avionics diagnostics pilot study (state-of-the-art assessment). AFHRL Contract No. F33615-81-C-0016, Task 82-1, Air Force Human Resources Laboratory, Wright-Patterson AFB OH, June 1982.

Westinghouse Electric Corporation. Logistics feasibility and team training impact studies interim report. AFHRL Purchase Request No. FY8993-82-00012, Air Force Human Resources Laboratory, Wright-Patterson AFB OH, July 1982.

Wohl, Hoseph G. Diagnostic behavior, system complexity, and repair time. Unpublished technical report No. M80-00008, The MITRE Corporation, Bedford MA, April 1980.

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